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LAWRENCE TECHNOLOGICAL UNIVERSITY

A. Leon Linton Department of Mechanical Engineering

Development of a Model-Based Systems Engineering Application to Analyze the Ground Vehicle Robotics Sustainment Industrial Base

a Dissertation Proposal submitted in partial fulfillment of the degree requirements of:

Doctor of Engineering in Manufacturing Systems (DEMS)

by

Garett S. Patria



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List of Acronyms

2D	Two Dimensional
3D	Three Dimensional
AD	Axiomatic Design
AHP	Analytic Hierarchy Process
AMSAA	Army Materiel Systems Analysis Agency
ANSI	American National Standards Institute
A _o	Operational Availability
AoA	Analysis of Alternatives
APS	Advanced Planning and Scheduling
AR	Army Regulation
ARC	Automotive Research Center
ARCIC	Army Capabilities Integration Center
AL&T	Acquisition, Logistics, and Technology
APICS	Association for Operations Management
ASAALT	Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASEC	Advanced Systems Engineering Capability

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ASME	American Society of Mechanical Engineers
ATP	Advanced Technology Program
AutoSoft	Journal of Intelligent Automation and Soft Computing
AUVSI	Association for Unmanned Vehicle Systems International
AV	Augmented Virtuality
BCITs	Brain-Computer Interaction Technologies
BOM	Bill of Material
C3V	Cortically-Coupled Computer Vision
CAD	Computer Aided Design
CAPS	Center for Advanced Purchasing Studies
CFAR	Collaborative Forecasting and Replenishment
CHASM	Collaborative High Speed Adaptive Supply Chain Model
CCIMPLEX	Consortium for Intelligent Integrated Manufacturing Planning-Execution
COTS	Commercial-Off-The-Shelf
CPFR	Collaborative Planning, Forecasting, and Replenishment
CPS	Cyber-Physical System
CSCMP	Council of Supply Chain Management Professionals
CY	Calendar Year

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DA	Department of the Army
DBS	Decision Breakdown Structure
DEMS	Doctorate of Engineering in Manufacturing Systems
DFL	Design for Logistics
DFM	Design for Manufacturing
DFS	Design for Supportability
DFS	Design for Sustainment
DM	Decision Management
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DoC	Department of Commerce
DoD	Department of Defense
DODAF	Department of Defense Architectural Framework
DOE	Design of Experiments
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities
DS	Distributed Simulation
DSM	Design Structure Matrix
DSPO	Defense Standardization Program Office

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ECP	Enterprise Collaborative Portal
EECOMS	Extended Enterprise Coalition for Integrated Collaborative Manufacturing Systems
EEG	Electroencephalography
EEP	Enterprise Expertise Portal
EIA	Electronics Industry Alliance
EIP	Enterprise Information Portal
EKP	Enterprise Knowledge Portals
EJOR	European Journal of Operational Research
ERP	Event-Related Potential
EUABs	Equivalent Uniform Annual Benefits
FMEA	Failure Mode Effects Analysis
FR	Functional Requirement
GUI	Graphical User Interface
GV	Ground Vehicle
GVR	Ground Vehicle Robotics
GVSETS	Ground Vehicle Systems Engineering Technology Symposium
HC	Human Capital
HIIT	Helsinki Institute of Information Technology

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HLA	High Level Architecture
IB	Industrial Base
IBET	Industrial Base Engineering Team
IEEE	Institute of Electrical and Electronics Engineers
IFPSM	International Federation of Purchasing and Supply Chain Management
IJSI	International Journal of Social Inquiry
ILAP	Integrated Logistics Analysis Program
ILSC	Integrated Logistics Support Center
INCOSE	International Council on Systems Engineering
INFORMS	Institute for Operations Research and the Management Sciences
IPSERA	International Purchasing and Supply Education and Research Association
IRSPP	International Research Study of Public Procurement
ISCMS	Logistics and Supply Chain Management Society
ISM	Institute for Supply Chain Management
ISO	International Organization for Standardization
IT	Information Technology
JCIDS	Joint Capabilities Integration Development System

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JMTM	Journal of Manufacturing Technology Management
JOM	Journal of Operations Management
JOSCM	Journal of Operations and Supply Chain Management
KT	Kepner Tregoe
LCMC	Life Cycle Management Command
LE	Logistics Engineering
LHS	Latin Hypercube Sampling
LSS	Lean Six Sigma
M&S	Modeling & Simulation
MBE	Model-Based Engineering
MBSE	Model-Based Systems Engineering
MDSD	Model-Driven System Design
METP	Materiel Enterprise Transformation Plan
MIT	Massachusetts Institute of Technology
MODAF	Ministry of Defense Architectural Framework
MOM	Model of Models
MR	Mixed Reality

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NAF	North Atlantic Treaty Organization Architectural Framework
NAPA	National Association of Purchasing Agents
NASA	National Aeronautics and Space Administration
NDIA	National Defense Industrial Association
NIGP	National Institute of Governmental Purchasing
NIST	National Institute of Standards and Technology
NPR	NASA Procedural Requirement
NSF	National Science Foundation
OBSE	Object-Based Systems Engineering
Op Tempo	Operating Hours
ORSA	Operations Research Society of America
OSMIS	Operating and Support Management Information System
P&IM	Production & Inventory Management
PAT	Process Analytical Technology
PBD	Platform-Based Design
PCM	Pacific Conference on Manufacturing
PDS	Parallel and Distributed Simulation
PM	Program Manager

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PMAC	Purchasing Management Association of Canada
Pro/E	Pro Engineer
PS	Parallel Discrete-Event Simulation
PTC	Parametric Technologies Corporation
QbD	Quality by Design
QbI	Quality by Inspection
QbT	Quality by Testing
QFD	Quality Function Deployment
RFP	Request for Proposal
RSVP	Rapid Serial Visual Presentation
RTI	Run Time Infrastructure
SA	Situational Awareness
SA	State Analysis
SB	Sequential Bifurcation
SC	Supply Chain
SCC	Supply Chain Council
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference

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SCRM	Supply Chain Risk Management
SD	System Dynamics
SE	Sustainment Engineering
SE	Systems Engineering
SME	Subject Matter Experts
SMEs	Small and Medium Enterprises
SOW	Statement of Work
SPRDE	Systems, Planning, Research, Development, and Engineering
SWA	South West Asia
SWaP+C	Space, Weight, Power, and Cooling
SWaP+C+L	Space, Weight, Power, Cooling, and Logistics
SysML	Systems Modeling Language
TACOM	Tank Automotive Command
TARDEC	Tank Automotive Research Development and Engineering Center
TDP	Technical Data Package
TIMS	Institute of Management Sciences
TKK	Helsinki University of Technology
TOGAF	The Open Group Architecture Framework

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TRANSNAV	International Journal of Marine Navigation and Safety of Sea Transportation
TRIZ	teorija rezhenija izobretalenskikh zadach (Russian for theory of inventive problem solving)
UML	Unified Modeling Language
UNCTAD	United Nations Conference on Trade and Development
UPDM	Unified Profile for DODAF and MODAF
USD	U.S. Dollars
VIICSO	Voluntary Inter-Industry Commerce Standards Organization
VSM	Value Stream Mapping
VSR	Virtual Situation Room
VTT	Technical Research Centre of Finland
WBS	Work Breakdown Structure
WCCI	World Congress on Computational Intelligence
WILD	Web Integrated Logistics Designer
WSC	Winter Simulation Conference
WTO	World Trade Organization WTO

Abstract

The U.S. industrial base is revered by the Department of Defense as a vital asset that needs to be managed, so it can remain intact to support equipment, and even flourish, over an acquisition system's entire life cycle. The U.S. Army obligates billions of dollars of resources towards the production and sustainment of equipment linked to an industrial base that lacks in analysis research, virtual experimentation, and sustainment risk analysis. A plethora of supply chains subject to varying support philosophies, supply and demand instability, and intellectual property bias give rise to a socio-economic system that is difficult to understand, monitor, protect, and augment, using only two-dimensional spreadsheets. Logistics Engineering and Model-Based Systems Engineering are imminent disciplines that have a synergy potential to integrate sustainment modeling and simulation into all phases of an acquisition system's life cycle. Facilitating this synergy will help give equal consideration to logistics and industrial base ramifications of equipment systems design decisions, ensuring that fielded systems are maintainable and ready for operations.

This research offers an enhanced situational awareness of the Tank Automotive Research Development and Engineering Center Ground Vehicle Robotics industrial base. Opportunities exist to investigate industrial base attributes proactively and expose multi-dimensional patterns, using proven computer aided design, problem solving, and visual analytics methodologies, popular in the automotive and app development industries. Secondly, this research proposes to conduct risk assessments, using discrete-event simulation tools, to leverage prioritized taxonomies and relationships inherent to the Ground Vehicle Robotics sustainment industrial base. Through the successful deployment of SysML, the modeling language of systems

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engineering, multi-model orchestration will demonstrate that the momentum of commercial-off-the-shelf collaboration technologies can interact, providing a strategic lens with which to specify, analyze, design, and verify Ground Vehicle Robotics platform support strategies. Fostering a user interface that allows analysts to travel from a macro-level analysis space towards a low-level solution space is considered to be of high-value to the Army. Since industry standard tools already exist for managing the chaos of distributed users constantly accessing, analyzing, and modifying requirements, behavior, structure, and parametrics, this research proposal aims to develop such a Model-Based Systems Engineering application to analyze the ground vehicle robotics sustainment industrial base.

Background

Defense organizations employ many individuals whose missions revolve around ensuring a healthy industrial base (IB) to supply equipment over a prolonged life cycle. These missions should consist of global situational awareness (SA), resource management, systems monitoring, and proactive analysis. The various IB missions have been growing more critical as military equipment experiences production declination and materiel enters the sustainment phase of the lifecycle. The sustainment phase entails low demand orders spread out over long periods of time that can exceed fifty years (McLeary, 2012; Office of the Assistant Secretary of the Army Acquisition Logistics and Technology, 2012). The inevitable transition from production to sustainment is forcing military equipment suppliers to think twice about whether they should suffer miniscule sustainment volumes or leave the defense market altogether in search for higher profit margins associated with commercial market production.

The criticality of a healthy U.S. IB was ultimately confirmed by the success of WWII and has even been deified by philosophers, like Ayn Rand (1957). The IB is still revered today as something that needs to be understood, monitored, and protected. This is the reason for the plethora of regulations, guidelines, policies, and directives that emphasize the importance of integrating IB considerations into systems design. For example, Army Regulation (AR) 700-90 1-7 says to:

Integrate industrial base planning into all phases of the acquisition system's life cycle. Relevant information will be gathered and maintained in order to describe the current industrial base, identify critical sectors and producers, document major shortfalls, identify trends, recommend corrective

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actions, and identify areas of concern for further study based on future Army requirements, if needed. Risk analysis, using industrial capability criteria in the excerpt from DODD 5000.60 will help make sound affordability decisions.

In addition, MIL-STD-499B (1994) recommends improved integration of systems requirements through: life cycle risk management, the elimination of functional stovepipes, and the tailoring of Commercial-Off-The-Shelf (COTS) items.

A truly robust equipment solution involves not only upstream Design for Manufacturing (DFM) practices, but involves ensuring that the manufacturing infrastructure will remain intact over the entire life cycle. It is important to realize that manufacturing, in and of itself, is merely fiction, unless there is an IB to foster it. Secondly, actual supply chains are just subsets of the “IB” connotation, since the IB includes untapped capabilities and capacities as well. In other words, the IB takes in the art of the possible, as well, which delves into social structure, business development, and collaboration potential. In a sense, the study and preservation of the IB (the parent) is even a higher calling than just advancing the “state of the art” in manufacturing (the child).

Quite often, “people won’t make a decision on manufacturing something if they don’t know their supply is reliable” (Lifton, 2012). This supply influence holds true for whether or not to conduct combat operations as well. Therefore, the outcome of supply and IB analysis affects national security and the United States’ ability to project forces. The IB consists of diverse businesses comprised of ever changing workforces and entrepreneurial potential that could convert to

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technological breakthroughs at any moment, making existing inventory obsolete. The IB is constrained by geographic and political boundaries (i.e. Congressional districts), dynamic litigation, rights to intellectual property, and global economic trends. Like an apparition, embracing the concept of the entire IB is an overwhelming domain to grasp and is even more challenging to analyze. Yet, acquiring SA of the IB should preclude the design of equipment support strategies.

The defense workforce is experiencing a perfect storm of information overload, staff attrition, old-fashioned office tools, and defense spending cuts, giving way to poor collaboration and low productivity among IB analysts and strategic planners (Bean, 2011, p. 7). With many Vietnam-era professionals leaving the workforce, a new breed of analysts are having to quickly learn unfamiliar jargon, industries, and even resources that cut across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) elements of DoD processes (e.g. Joint Capabilities Integration Development System [JCIDS]). Continually unearthing multitudes of legacy Information Technology (IT) systems and perpetually establishing networks of colleagues only induces more stagnation into a steep learning curve.

Camps of federal employees analyzing individual aspects of the IB are spread over multiple hierarchies, locations, and agencies, each with their own history, culture, and mission. For example, although TARDEC Systems Engineers (SEs) are beginning to work more sustainment tasks, the Integrated Logistics Support Center (ILSC) houses the core Logisticians who are more known to deal in Tank Automotive Command (TACOM) sustainment concerns, while the

Product Support Managers lead the effort for the Program Managers (PMs) and are responsible for sustaining operations over their equipment's life cycle. TARDEC has acknowledged a workforce culture rejuvenation and has stood up the Logistics Engineering (LE) philosophy and accompanying curriculum to help bridge the gap between the multiple groups and processes influencing sustainment. LE adds a new dimension to the old Payload-Protection-Performance tradeoff paradigm of Figure 1 below (Bochenek, Benson, & Ramdass, 2011, p. 10).

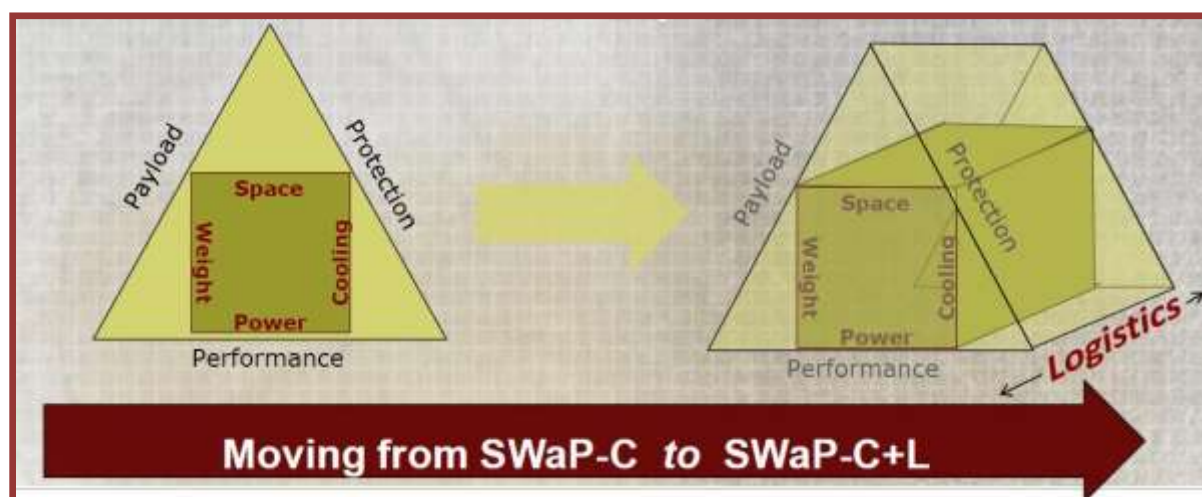


Figure 1: Paradigm change to a logistics frame of mind

As illustrated in Figure 1, a new horizon of analysis is being emphasized by senior leadership, signifying that an equal consideration be given to the logistics ramifications of equipment design decisions. The word logistics includes “planning and executing the sustainment of forces and equipment in support of military operations” (Bean, personal communication, November 15, 2011). The major focus of sustainment logistics is to ensure that fielded systems are maintainable and ready for operations. Frankly, Army Regulation AR 70-1 formally states that “supportability analyses must be conducted as an integral part of the systems engineering (SE)

process (2011, p. 4). Since the IB is the source that feeds the instruments of sustainment and supportability, from a product stand point, the modeling and simulation (M&S) of the IB should also be integral to success. Army Regulation AR 70-1 also states that “the use of M&S should be considered throughout all modifications and upgrade efforts, as well as measuring supportability and military worth” (2011, p. 4). Therefore, LE practices are being preached throughout TACOM, in an effort to better understand the biggest culprit of life cycle costs, as portrayed in Figure 2 below (Patria, Bean, & McCauley, 2012).

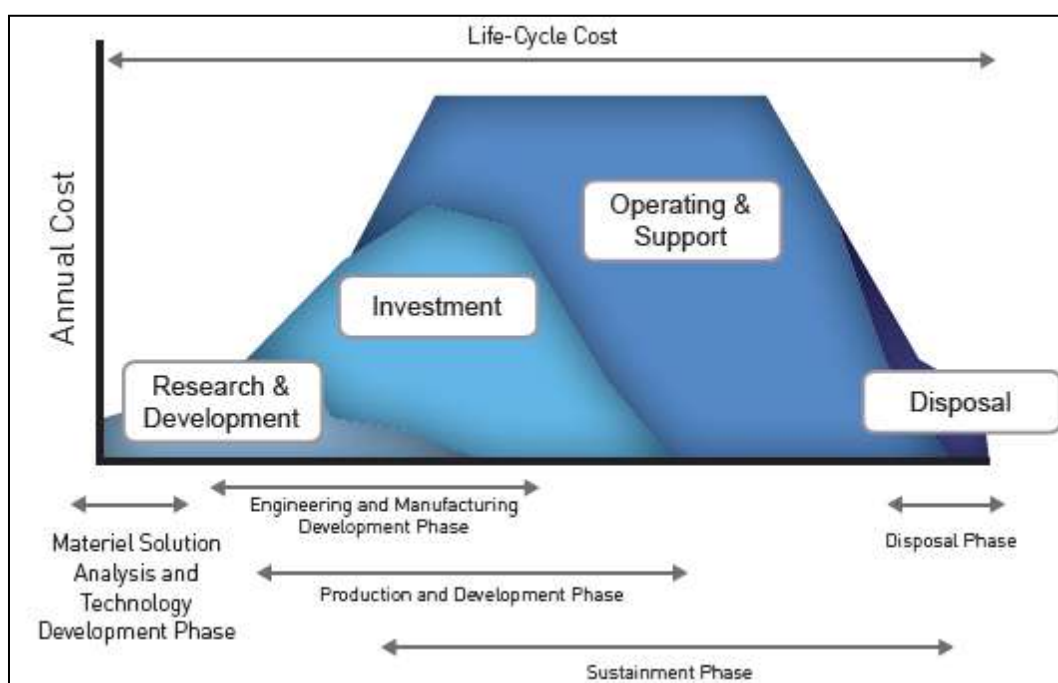


Figure 2: Constituents of life cycle cost

TARDEC has fueled the Design for Sustainment (DFS) movement, also, by executing the Human Capital (HC) initiative. The HC initiative weighed the short and long term skills needs of TARDEC with the current and future staff, respectively (TARDEC G1, 2010). The lessons learned from the HC initiative revealed that improved capabilities in information technology

(IT), communication and strategic thinking are in higher demand than just the traditional skill sets of the past (e.g. mechanical engineering). Uncovering new M&S techniques for analyzing strategic IB information is a research area that answers the call for IB analysis, while fulfilling the gaps identified in the HC initiative. Therefore, a collaborative IT design solution that solves problems for the modern acquisition workforce is considered to be of high value.

Using graphics to visualize data enables teams to recognize patterns and trends that would normally be hidden from sight (Huntley, 1970; Patria, 2000; Järvinen, Puolamäki, Siltanen, & Ylikerälä, 2009; Saylor, Meyer, Wilmes, & Moore, 2011). More sophisticated graphical analytics, like Dorian Shainin's ISOPLOT, even offer novel insight into the robustness of measurement systems (Steiner, MacKay, Ramberg, 2008). Capitalizing on the perception and cognitive abilities of the human eye-mind system has proven to offer leverage, during analysis, for centuries. One of the more famous examples in history, developed by Pierre Vernier, involves exploiting the capability of the human eye to accurately judge colinearity. Essentially, the Vernier scale allows users to repeatedly pinpoint a measurement on a continuous scale, with attribute-like precision, beyond (ten times) the competence of resolution available to the unaided eye. Spatial awareness through scientific visualization also delves into graph theory and the study of the space-time continuum (Economou, personal communication, June 21, 2012). Huntley (1970) proposed that the distance intervals between geometric elements and forms are instinctive to corresponding travel time intervals, due to the number of nerve impulses associated with the muscular effort of the eyeball as an on looker's eyes traverses along an edge. Failing to represent systems as graphs and geodesics, simply overlooks the prospect of concealed relationships. Enter the craft of visual analytics: the science of analytical reasoning and decision

making from interactive data visualizations (Järvinen, Puolamäki, Siltanen, & Ylikerälä, 2009). The recent boom of the “app” market, with its subtle incorporation of haptics, also demonstrates the power of amassing hidden resources in that intelligent use of data visualization enables diverse participation.

Seeking new knowledge in the area of IB analysis using visual analytics, within the context of a modeling paradigm that encompasses the entire IB mission, presents new opportunities for experimentation. The Army Capabilities Integration Center (ARCIC) defines experimentation as:

an analytical activity, founded upon observation or experience derived from unbiased trials conducted under controlled conditions within a representative environment to discover something unknown, to test a hypothesis, or demonstrate some knowledge within a specific context. Army experimentation is the conduct of experiments involving Soldiers and leaders within live, virtual and constructive environments for exploring concepts, capability requirements and solutions across DOTMLPF domains, in order to learn and mitigate risk for current and future forces. Experimentation exists to gain knowledge, in order to reduce risk to Soldiers and investments and is uniquely suited for concept development. This is due to the fact that experimentation creates complex, uncertain environments and allows for innovation – creating new knowledge. Overall, experimentation provides an integrating analytical infrastructure for assessment across: 1) Warfighting functions and DOTMLPF, 2) academia, industry, government, and 3) joint, interagency, intergovernmental & multinational domains. Experimentation has value, because understanding is essential for

decisions – for concepts, requirements and solutions. In addition, experimentation is deemed valuable to the Army, due to the understanding gained by learning, in that knowledge must be developed in a manner suitable to the problem. Constructive analysis is suitable for complicated problems. Experiments uniquely provide complex environments – an essential complement to other learning methods. (Maculley, 2012).

This research proposal is the result of a synthesis of three distinct requirements from three interconnected domains, as depicted in Figure 3 below (Stefanopoulou, 2010).

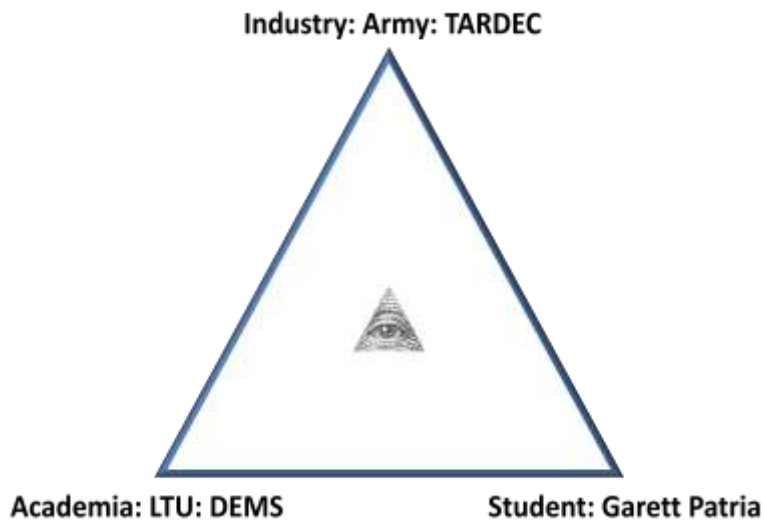


Figure 3: Triad of dissertation requirements

The following vision and mission statements corresponding to Figure 3 embody the overarching expectations of each domain:

TARDEC

Vision:

Be the recognized Department of Defense leader for ground systems and combat support systems technology integration and systems-of-systems engineering across the life cycle

Mission:

Provide industrial engineering support for the U.S. Industrial Base Operations mission and the Diminishing Manufacturing Sources and Material Shortages (DMSMS) initiative. Provide industrial engineering expertise and experience to investigate, manage, and resolve industrial base issues related to production and sustainment of military equipment

Lawrence Technological University (LTU) Doctorate of Engineering in Manufacturing Systems (DEMS)

Mission:

Solve appropriate dissertation problems that arise from the manufacturing facility which when solved will have relevance to advancing the 'state of the art' in manufacturing. The result may be a new manufacturing related device, process, system, or software for which high-level scholarship engineering expertise and ingenuity are required to find the solutions

Garett Patria

Mission:

Formulate a research area that leverages my passion, unique skills, and current opportunities and resources

Expanding on each of the three aforementioned domains, preliminary research was conducted between 2010 and 2012 to gather actual results (e.g. documented systems attributes, Army efforts consuming tangible resources) that exemplify and expand on the priorities of the three domains of Figure 3. A storyboard of the expanded domains was maintained to map out the flow of interconnected themes and is shown below in Figure 4.



Figure 4: Storyboard used for DEMS proposal strategic planning

A digital representation of the actual storyboard was also created to summarize the findings of the domain pre-research, along with a narrated, three-part video explaining each section that was used to brief targeted DEMS academic and industrial advisors (see Figure 5).

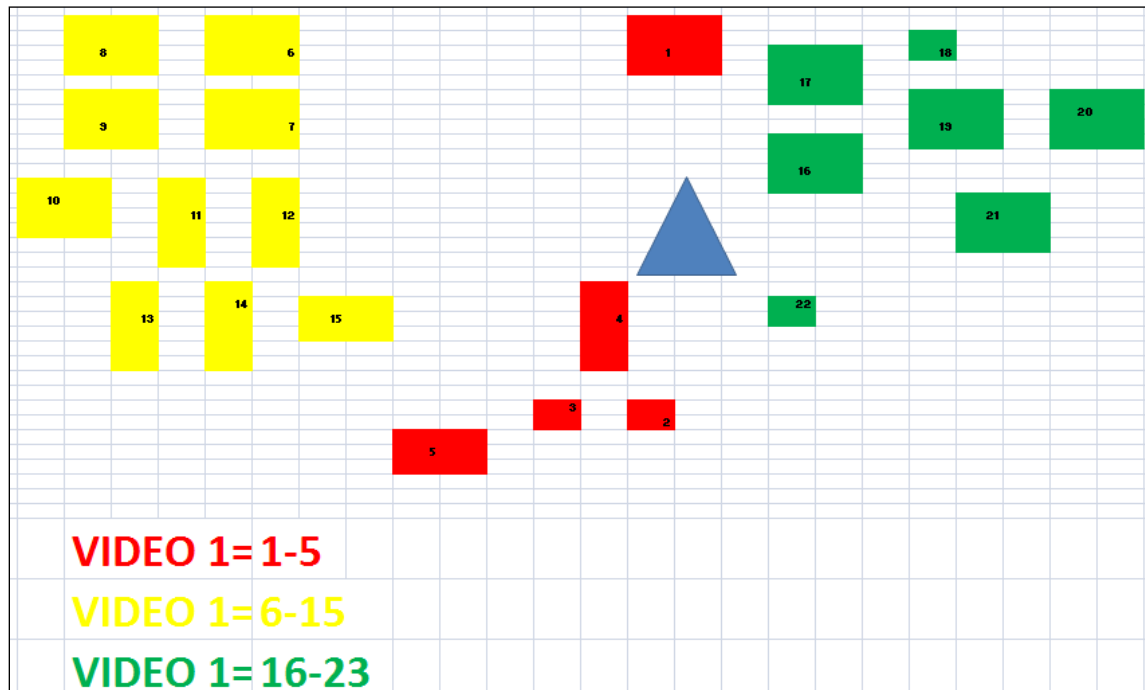


Figure 5: Digital representation of storyboard of Figure 4

A concise list outlining each numbered element of the premeditated storyboard is shown below:

Red Section or “Student” Domain:

1. DEMS call to “create new knowledge” linked with my mission at TARDEC
2. traits and behaviors that make me a doctoral candidate
3. subjects I want to explore in the future
4. a list of results-to-effort considerations

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5. organizational structures showing how manufacturing systems falls under the Logistics realm (in terms of Acquisition, Logistics, and Technology); but, in terms of the Systems, Planning, Research, Development, and Engineering (SPRDE) career field, manufacturing systems is considered an SE discipline. SE is the discipline under which I was hired

Yellow Section or “Employer” Domain:

6. the top three TARDEC competencies needed within the next five years (CY2010 – CY2015) were found to be: Visionary, Strategic Thinking, and Systemic Thinking (TARDEC G1, 2010)
7. the top three TARDEC competencies needed within the six months spanning from Jun 2010 to Dec 2010 were found to be: Proactive, Communication, and Relationship Building (TARDEC G1, 2010)
8. the top three CY2010 contributors to TARDEC success were found to be: Customer Focus, Technical Proficiency, and Problem Solving (TARDEC G1, 2010)
9. the second goal of the 2009 Department of the Army (DA) Materiel Enterprise Transformation Plan (METP) is to ensure a viable Industrial Base (Department of the Army, 2009)
10. the TARDEC Director’s call to reduce unintended consequences through a paradigm shift from a Space, Weight, Power, and Cooling (SWaP+C) mind-set to a Space, Weight, Power, Cooling, and Logistics (SWaP+C+L) mind-set, where Logistics represents a third dimension, introducing depth to the old SWaP+C 2D model. Logistics encompasses the

Commonality, Durability, Transportability, Supportability/Maintainability, and Producibility disciplines (Bochenek, Benson, & Ramdass, 2011, p. 10)

11. the Office of Management and Budget (OMB) nomenclature and funding (e.g. 6.1, 6.2, 6.3) distinctions explaining Basic Research (i.e. 6.1), Applied Research (i.e. 6.2) and Advanced Technology Development (6.3 funding), which are transcribed below (OMB, 2012; Rand Corporation, 2012; Sargent, 2012; Coyle, 2011, p.17):

Basic Research:

Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind

Applied Research:

Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met

Advanced Technology Development:

Includes all efforts that have moved into the development and integration of hardware for field experiments and tests

12. a hierarchal depiction of the different levels of research visibility (e.g. National Science Foundation (NSF) vs. International Council of Systems Engineers (INCOSE)) and

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organizational support that should be considered when conducting research (Ali, personal communication, October 2010)

13. a preliminary list of hot topics observed within TARDEC - the beginning stages of a Pugh Analysis on DEMS dissertation proposal titles
14. an Acquisition, Logistics, and Technology (AL&T) Online article announcing the AL&T 2010 M&S Award – this storyboard element shows the unique opportunities associated with particular areas of research
15. a list explaining the considerations of choosing to conduct DA research, as opposed to private research not affiliated with the DA nor any of its requirements and restrictions (part of the aforementioned Pugh Analysis)

Green Section or “School” Domain:

16. a commonality matrix identifying overlapping key words between the requirements of the aforementioned domains of: my employer, my school, and myself – this matrix was considered when constructing the title of this dissertation proposal
17. the initial vision, mission, and strategic goals to generate and formally document a DEMS dissertation proposal - treating the DEMS dissertation like a business entity, in and of itself (Shenkus & Sloss, personal communication, May 12, 2010)
18. the initial matrix of deadlines required to transform the DEMS dissertation strategic objectives into goals (Taraman, personal communication, June 1, 2010)
19. the initial Gantt Chart used to track DEMS goals and progress

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20. a Concept Diagram depicting the relationship of prevalent dissertation topics as a function of literature search workload (time) – a consideration pertaining to Lloyd Alexander’s theory that suggests we learn more by looking for the answer to a question and not finding it than we do from learning the answer (Dr. Jeff Abell, personal communication, 2010)
21. a characterization of a historical sample of DEMS dissertations depicting data content as a function of total length (as measured in pages)
22. a synopsis of potential divergence between potential research areas, mission alignment, and perceived deadlines

Other various chronicles leading up to this research proposal are included in Appendix B. The chronicles offer additional transparency into the development of the proposed topic for doctoral study.

In terms of how the DA is formally planning for the future and what technologies TARDEC should be working on, ARCIC provided insight, during a brief to TARDEC on 25 Oct 2012, emphasizing the 1) emergence of M&S applications and 2) experimentation opportunities.

ARCIC feels TARDEC should integrate more developed models into everyday practice, in order to sustain the organization of the future.

Problem Statement

TARDEC does not have a holistic model that identifies and integrates the requirements, behavior, structure, and parametrics of the Ground Vehicle Robotics sustainment industrial base.

Literature Search

This dissertation proposal touches on five disciplines, each with their own league of scholarly publications and host of gatherings that incubate research findings. The five disciplines include: 1) 3 Dimensional (3D) visualization, 2) military sustainment, 3) supply chain management, 4) systems engineering, and 5) robotics. The robotics discipline was included in the literature search, since it serves as the proposed platform of focus for this research. Robotics is well known for its out-of-the-box culture of researchers who often motivate technology and generate fast prototypes on lean budgets. Specifically, robotics platforms typically deal with smaller Bills of Materials (BOMs) and supply chains, so more emphasis can be placed on the theme of the research, as opposed to the superfluous part counts associated with stereotypical heavy combat equipment, for example. Finally, one of the primary depots for robotics overhaul is considered local, creating a unique opportunity to explore a significant aspect of the platform's supply chain without expending scarce travel resources.

The literature reviewed in this proposal was chosen based on how it applied to the research vision of the author. During the literature search, key aspects of the literature were recorded in a comprehensive, bibliometric model that also served as a repository, or e-diary, to house notes and subsequent hyperlinks to information offering more granularity (see Figure 6).

	A	B	C	D	E	F	G	H	I
1	Papers	Author	Title	Document Yr	Date	Society	Location	Pgs	Cost
75		Shangping Gong	A-Explosion Concepts and Measures of Manufacturing	2000	2000	2000	2000	2000	2000
76	28	Sanborn-Kiang	BOLH = Nearly Orthogonal Latin Hypercube meta models = collection of concepts within a certain domain = a model's map						
77		Mary-McInerney	regression meta models						
78	28	Long A. Peterson	single polynomial meta models						
79	28	Brady-Jarvis	MCDD = matrix corps decision support system						
80		Pekko-Gilman	extended price = cost + QTY						
81		Makoto-Hironaka	QTY quantity = number of parts per weapon system						
82	21	Shigehiko-Gotoh	criticality code = 5 (vital)						
83	21	Shigehiko-Gotoh	level of repair = depot or intermediate level						
84	21	Shigehiko-Gotoh	optimum						
85	21	Shigehiko-Gotoh	stockout = running out of stock						
86	21	Shigehiko-Gotoh	design points = scenarios						
87	21	Shigehiko-Gotoh	MPF = Naval Post Graduate School						
88	21	Shigehiko-Gotoh	orthogonal = perpendicular, independent, separate, etc.						
89	21	Shigehiko-Gotoh	time-persistent variables (fully, time-persistent, and counter) = ex. how long (on average) the queue is						
90	21	Shigehiko-Gotoh	spreaded = added						
91	21	Shigehiko-Gotoh	capital discount rate (TR) = IRR						

Figure 6: Bibliometric interface

Note how Figure 6 exhibits some of the key information of each piece of literature, such as: author, title, document type, date, society, location, and number of pages. Since the root interface of the bibliometric model is a pivot table, the resultant pivot charts provide a visual gage to communicate the breadth and depth of the literature search.

An important first step of the literature search was to simply identify the various professional organizations (societies, conferences, etc.) and publications (journals, dissertations, etc.) that pertain to the five disciplines (i.e. 3D visualization, military sustainment, supply chain management, systems engineering, and robotics). Over one hundred organizations/publications were considered, during the literature search, in a strategic effort to capture more breadth than depth. Literature breadth was considered primary and depth considered secondary, due to: 1) the multi-domain philosophy advocated by the systems engineering discipline and 2) the author's supplementary depth of field experience in the IB analysis domain.

In general, the organizations and publications have a reputation that ranges across 427 years, the oldest being Cambridge University Press. The Thomson Reuters™ 2-year impact factors for some of the publications were superimposed over a Pareto Chart showing when the respective

organizations and publications were founded (see Figure 7). For the full list of organizations and publications explored in the pre-research, please see Appendix A.

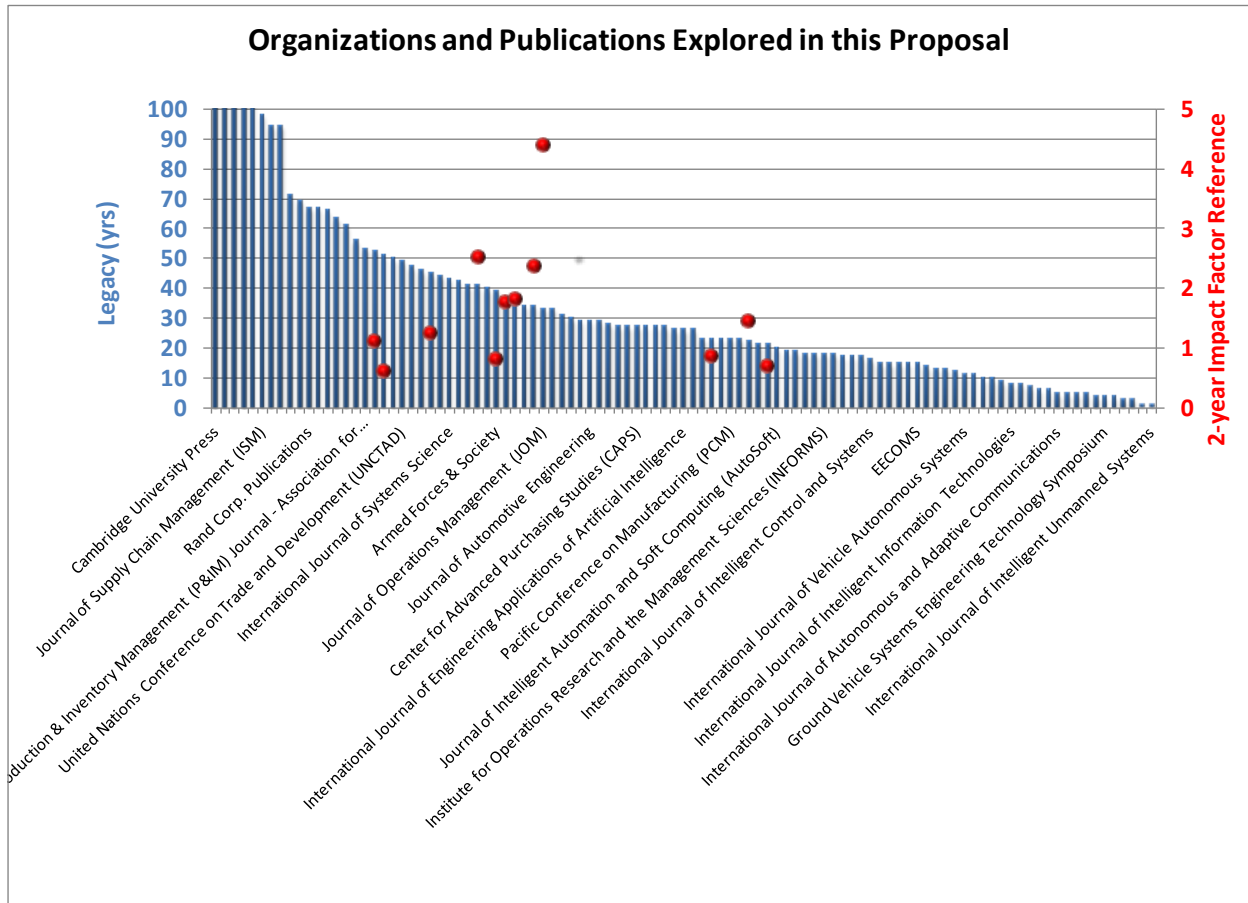


Figure 7: Legacy and relative impact factors of select organizations and publications

Out of the 101 organizations and publications discovered, 129 scholarly articles were targeted and categorized, by type, whose distribution is depicted below in Figure 8).

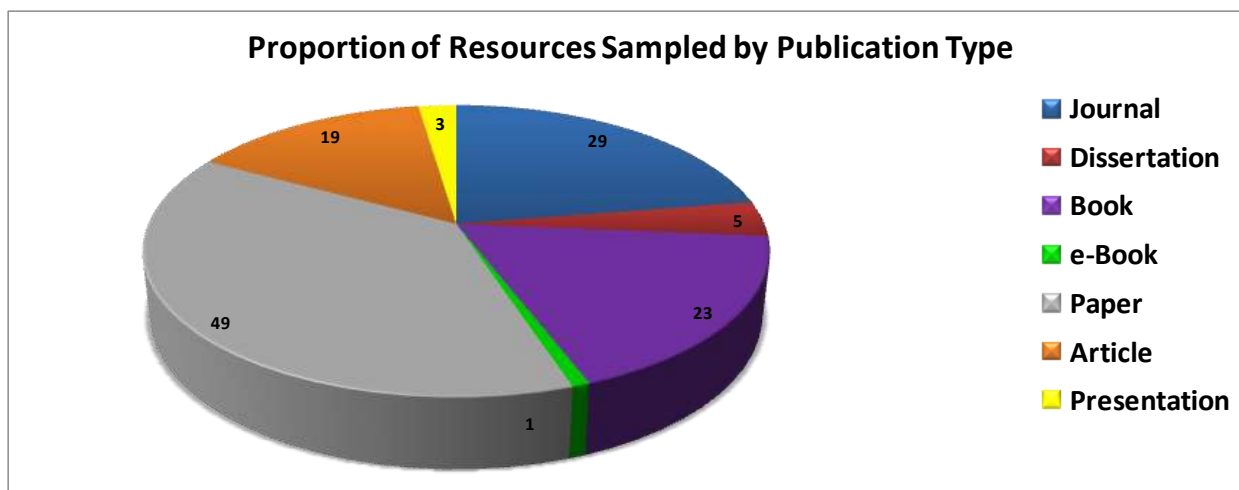


Figure 8: Categorization of scholarly literature

Another output of the bibliometric model takes the type of publication targeted and overlays an alphabetical listing of the authors, as well as the number of publications targeted per author (see Figure 9).

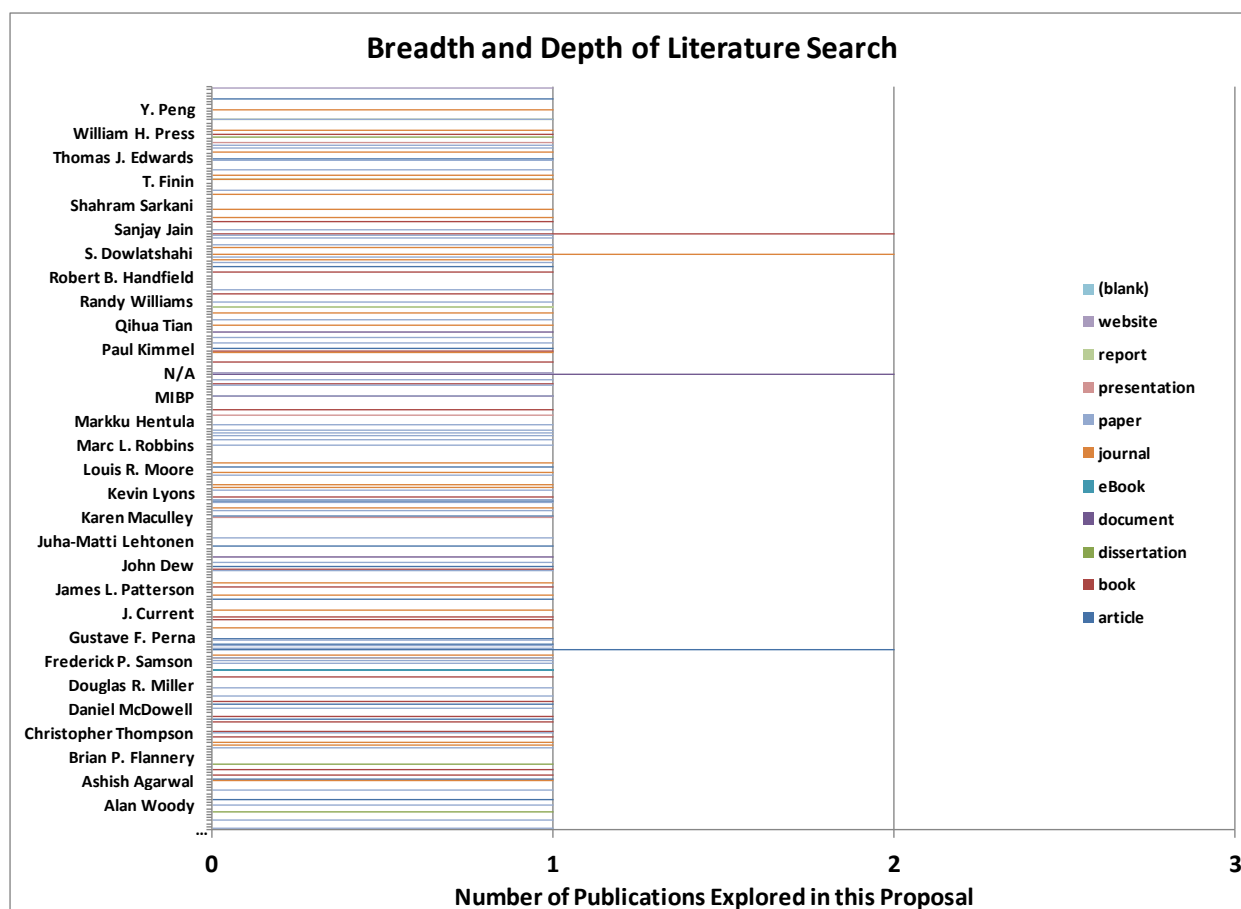


Figure 9: Literature type by author

The visual analytic output of the bibliometric model, like the analytic shown in Figure 9, gives research critics a set of gages to judge how well the literature was scoured. In the case of multiple authors for one piece of literature, options exist in the interactive bibliometric model to display one publication per author-team, if desired. Many other visual analytic outputs are possible, due to the COTS availability and familiarity of MS Office pivot table and pivot chart options.

Literature Review

The first three papers of the literature search chosen for review involve literature surveys themselves. Appelqvist, Lehtonen, & Kokkonen gathered bibliometrics of their own in that they examined 15 journals between 1997 and 2001 to classify various supply chain modeling papers in a framework, in order to match the modeling approach with the decision-making situation. The classifications in the decision-making framework included: 1) Continuous Improvement, 2) Re-engineering, 3) Design for Logistics (DFL), and 4) Breakthrough, depending on whether the supply chain, and product being supplied, was new or existing.

Articles which had a simulation approach were tallied against articles that had an optimization approach, noting the distinctions of both. The proportion of simulation versus optimization papers was considered balanced at 46 papers versus 39 papers, respectively. The European Journal of Operational Research (EJOR) had more papers than any of the other 83 papers (out of 15 journals surveyed) that matched the authors' survey criteria: 1) the paper must relate to a physical product and its supply chain in a business environment, 2) the paper must have a modeling approach, and 3) the paper must exemplify an actual case application utilizing real data. Considering all the papers surveyed, continuous improvement research was the most abundant, compared to the other three framework classifications. Although difficult to determine, the largest single industries covered by the sampled papers were the electronics, food, and automotive industries. Other categorical splits observed were: 38 cases utilized discrete part manufacturing versus 21 for process manufacturing (e.g. undifferentiated product).

Appelqvist, Lehtonen, & Kokkonen found that most research (i.e. 80 out of 83 papers) was conducted within the classifications involving existing product (i.e. continuous improvement and

re-engineering), as opposed to classification involving new product (DFL and breakthrough). Also, models were used more for one-time analysis, as opposed to continuous decision support. Finally, using a benchmark case study of a Patria Ltd (a Finnish defense company) aerospace structure development project, the authors observed that the 3D characteristic of simulation offered the most convincing aspect of analysis. Furthermore, simulation models that interact within an overarching information technology (IT) infrastructure and follow the product life cycle from concept to full-scale production are considered as obligatory.

Terzi & Cavalieri (2004) surveyed more than 80 articles, coined under the mantra of supply chain management, that deal in simulation and the industrial collaborative environment. Initiatives that adopt an external perspective on the design and implementation of new supply chain management strategies were reviewed. The authors determined that simulation's main property, what-if analysis, plays an important role in analyzing complexity problems associated with logistics networks. Among other quantitative methods like Advanced Planning and Scheduling systems (APS), Supply Chain Operations Reference (SCOR) modeling, linear programming, and genetic algorithms, simulation knowledge is one of the most important competencies for many different processes, including business, marketing, and manufacturing.

The coordination practices of running multiple simulations started around 1970 and were computationally divided into two general categories: analytic simulation (quantitative only) or distributed virtual environment (extensive use of visual analytics). It is important to note that the visualization capability of simulation was considered its own category, until the two categories merged into what is known now as Parallel and Distributed Simulation (PDS) paradigms, which

suggests that supply chain M&S can be a single model producing all nodes, or many parallel models cooperating in one simulation. Two major types of PDS include Distributed Simulation (DS) and Parallel discrete-event simulation (PS), depending on whether there are multiple computers geographically distributed or not. PDS, in general, is considered to be a worthy consideration, due to the following benefits: 1) simulation time reduction (segmentation principle), 2) PDS can accommodate the reality of geographically distributed human resources, 3) PDS has the capability to have each simulation model run in their native language, 4) reliability improvement through multi-node redundancy.

The PDS framework is divided into three schools of thought: 1) a network structure where all the distributed nodes continually interact with each other, 2) a centralized structure where dedicated software orchestrates messages from the distributed nodes and 3) High Level Architecture (HLA) which is based on ten ground rules for creating and managing the simulation. HLA was developed by the DoD and is considered to be the most known PDS framework (Terzi & Cavalieri, 2004). HLA involves an interface specification (i.e. IEEE 1516) and overarching software referred to as a Run Time Infrastructure (RTI). Terzi and Cavalieri claim HLA helps mitigate the risk of outside enterprises hoarding M&S data, which is a typical roadblock to harmonizing distributed systems. Finally, the authors tallied each of the 80 papers surveyed by various scope and objective subcategories. A key observation of the survey was that the local simulation paradigm is still the most applied approach and typically involves supply chain design and strategic model verification through expert reviews. The paper concluded, by suggesting future trends in supply chain simulation, including a need for more work involving PDS

applications. Two PDS projects discussed were the Web Integrated Logistics Designer (WILD) and the Osim project.

Kleijnen (2005) surveyed literature pertaining to four different types of supply chain management (SCM) simulation and discussed their methodological issues, while emphasizing the role of statistical methods for the design of experiments (DOE). The four types of SCM simulation included: 1) spreadsheet simulation (i.e. corporate modeling), 2) system dynamics (SD), 3) DES, and 4) business games. Kleijnen defined simulation as an experimental method where analysts experiment with various factors and model structures. The characteristics of SCM simulation models include: 1) they are quantitative, 2) they are transient, and 3) they are not solved by stand-alone mathematical analysis. The proper simulation type is determined by the type of “what-if” input in which the tradeoffs are: 1) validation and verification, 2) sensitivity, 3) optimization, and 4) risk and robustness analysis. Kleijnen emphasized that simulation is important, because it supports the quantification of benefits resulting from SCM and, thereby, guides decisions through multiple zoom levels (i.e. strategic, operational). The educational value and analytical derivation power of various connotations of human behavior modeling (i.e. gaming) was discussed as well. Kleijnen found that strategic and operational game modeling is much more difficult than simulating technological and economic processes. DOE models treat systems as black boxes, unlike most simulation models (exceptions include perturbation and score function methods). One of the noted phenomena, deemed a *bullwhip* effect within the SD portion of the survey, was the amplification of demand fluctuation, due to varying strategies in how deviations between actual and target inventories were managed. SD was deemed to view companies as systems with six varieties of input and output flows: 1)

materials, 2) goods, 3) personnel, 4) money, 5) orders, and 6) information. On the other hand, the DES portion of the survey exposed that DES has two distinguishing characteristics: 1) it represents individual events and 2) it allows for stochastic inputs and outputs. A strategic DES case study was conferred that consisted of three simulation models representing three alternative supply chain designs. In the case study, the most important factors were screened by sequential bifurcation (SB), with replication, and assessed for how well the factors can be influenced by management. The SB enabled a focus on 49 potentially important factors, down from 92 (a reduction of almost 47%). A DOE was conducted, leveraging central composite design and latin hypercube sampling (LHS), along with a hypothetical Taguchi optimization demonstration. The *bootstrapping* method of confidence interval creation was then exemplified to properly deal with the nonlinear input functions of the simulation outputs. Overall, the experiment revealed that one of the factors (e.g. demand for product 1) accounts for 90% of the total demand of the supply chain. Finally, some of the differences were discussed between optimizing for mean, as opposed to variance, where the author expressed that it is more important to find robust solutions than the optimal solution.

Tolone (2000) presented that small reductions in inventory, facilitated by Virtual Situation Room (VSR) technology incorporating feature rich protocols, could result in billions of dollars of savings, since approximately \$1 trillion USD is tied up in inventory, globally. The structure of the paper was presented in three parts: 1) an overview of common manufacturing practices, 2) an explanation of the VSR collaboration technology solution, and 3) a VSR demo. Contested issues still relevant today, like lean contracting and technical data package (TDP) definition were covered.

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VSR research began in 1998 and is a result of the mission of the Extended-Enterprise Coalition for Integrated Collaborative Manufacturing Systems (EECOMS) which is to research, develop, and demonstrate technologies to enable the integration of manufacturing applications in multi-company supply chain planning and execution environments. In a related effort, the Department of Commerce (DoC), National Institute of Standards and Technology (NIST), and Advanced Technology Program (ATP) joined forces to create the industry-sponsored Consortium for Intelligent Integrated Manufacturing Planning-Execution (CIIMPLEX) as an initiative for advancing data sharing (Peng et al., 1999). Tolone stressed the importance of, both, asynchronous and real-time collaboration, as well as why no single supply chain model fits all manufacturing processes. The Supply Chain Operations Reference (SCOR) model proposed by AMR Research, Inc., for example, provided a visual analytic that depicted the planning, sourcing, making, and delivering activities. On the other hand, the Collaborative Planning, Forecasting, and Replenishment (CPFR) model proposed by the Voluntary Inter-Industry Commerce Standards Organization (VIICSO) based on Benchmarking Partners, Inc. Collaborative Forecasting and Replenishment (CFAR) work with Wal-Mart, stressed the importance of strategic planning sharing among large trading partners. Similarly, the Collaborative High Speed Adaptive Supply Chain Model (CHASM) suggests strategic supply and demand planning sharing amongst partners, but puts more emphasis on lightweight solutions, involving more human intervention, for situations that fall outside initial, strategic boundaries. The VSR vision focuses on providing a primitive connectivity to the human intervention outlet, by offering more of a knowledge workflow domain, through decentralized data and knowledge fragmentation, with various alarm conditions that provide a greater SA. Respecting the need for situational knowledge, a series of portals were proposed, including: 1)

Enterprise Information Portals (EIP), 2) Enterprise Collaborative portals (ECP), 3) Enterprise Expertise Portals (EEP), and 4) Enterprise Knowledge Portals (EKP). These portals, showcasing entities, termed zones: infospheres, teamrooms, commonpoints, virtual offices, and media spaces are comparable to the Facebook chats, Skype, SharePoint, and Google Docs tools of today.

Jain and Leong (2005) proposed a simulation model using Arena to determine the readiness of a supply chain providing equipment to a defense contractor. By depicting a virtual operation, the paper describes the reduction of perceived risk of sourcing from Small and Medium Enterprises (SMEs). The main steps presented were the evaluation of spiked demand scenarios, identification of limitations to supply, validation of supply chain configuration enhancements, along with corresponding results. Interestingly, the aforementioned SCOR model (Tolone, 2000) is another way to specify the project. Also, it was noted that SMEs have not enjoyed their fair share of supply chain simulation research. Through ten nodes, four stages, three Tier II suppliers, five Tier I suppliers, the SME itself, and the defense contractor, the model simulates normal operations, surges (two times normal volume), and mobilization (four times normal volume) scenarios. A questionnaire (with little response) also accompanied the study, in an attempt to satisfy two objectives: 1) simulation and 2) value stream mapping (VSM). The simulation was presented in the following order: 1) analysis of modeled phenomena, 2) formatting of the data, 3) the reading of the data into the simulation, 4) configuration of the simulation model, and 5) execution of the simulation runs. The importance of an M&S solution exhibiting a good graphical user interface (GUI) was underscored, along with the capability to interface with popular tools, like MS Excel. The output of the simulation tracked bottlenecks and capacities, while ensuring no back log orders at the SME. Investment in inventories ranged

from \$2.33M to \$3.62M USD to handle the surge volumes and a \$5.62M investment was simulated to accommodate the mobilized volumes.

The lessons learned from the study included: 1) committing enough resources to gather data in a timely fashion, 2) using the right level of model abstraction, 3) focusing on only the critical data, 4) establishing the key output metrics up front, 5) building internal cross-checks to ensure the model is behaving logically, 6) validating the model with expert reviews, and 7) utilizing visualization techniques for improved understanding.

Kang and McDonald (2010) used Microsoft Excel spreadsheets and Arena models to generate life cycle cost and operational availability (A_o) responses, after varying component reliabilities, inventory of spares, operational tempo (Op Tempo), and repair turnaround times. The paper serves as a practical execution of COTS analysis tools. Regression Trees, described as “more human-readable”, were used to depict the threshold of where inner leaf, response variability diminishes and leaf-to-leaf response variability increases. The resulting DOE confirmed that A_o is an influential metric that correlates to life cycle cost and depends on repair part availability. However, the analysis assumes that a fruitful supply chain (and a parent IB) is a given.

Järvinen, Puolamäki, Siltanen, & Ylikerälä (2009) reported the findings of a joint visual analytics project, noting that the topic of information visualization has been an active research area since 1990. Executed in 2008, between the Technical Research Centre of Finland (VTT), the Helsinki University of Technology (TKK), and the Helsinki Institute of Information Technology (HIIT), the report introduced the concept and the state-of-the-art in the market. In addition, a demonstration tool developed in the project illustrated the concept. Finally, the report outlined

roadmaps for industrial and consumer applications. The building blocks of visual analytics were presented as: 1) information visualization, 2) data mining, 3) analytical reasoning, and 4) integrating data sources. The concept is based on how visualizations increase human cognitive resources, especially when viewed through different lenses or experience domains. Some of the aspects of human perception analyzed in the study include: processing visual symbols, human perceptual processing, human eye properties, visual attention, the Gestalt laws of pattern perception, visual objects perception, perception of distance and size, and visual interaction. Interactive visualizations that are characterized by a feedback loop can be further divided into three phases: 1) data manipulation, 2) view refinement and navigation (exploration and navigation), and 3) problem solving. On the other hand, visual grammars like Systems Modeling Language (SysML), are considered to be applications of Gestalt laws. Specialized software available in the market was presented to reside in the following domains: 1) office tools, 2) business intelligence tools, 3) statistical and mathematical tools, 4) visualization-related libraries and software packages, 5) algorithmic tools, 6) visual data mining tools, 7) web tools and packages, and 8) scientific visualization tools for modeling complicated physical phenomena. Short term and long term roadmaps for consumer and industrial application of visual analytics were forecasted in the following contexts: drivers, markets, products and solution, and technologies. Mobile, collaborative devices deploying haptic interfaces exemplify one of the long term prospects that the authors envisioned on the horizon.

Monczka, Handfield, Giunipero, and Patterson (2011) presented a study that was conducted in 2008 that considered visibility to be the number one capability that allows an organization to assess its supply chain risk management (SCRM). The secondary and tertiary capabilities

included early warning systems and supply chain analytics, so that risk events can be better understood.

Cristensen (2005) proposed that adding a third dimension to the traditional performance versus time visual analytic helps see disruptive innovation through a new lens. Adding “non-consuming occasions” to the axis system presents an additional view of the industrial base that allows the product model to start assessing untapped IB opportunities. Cristensen also presented a pyramid-shaped process where the bottom of the pyramid involves observing, describing, and measuring phenomena. Flowing upward, the middle of the pyramid involves categorizing the observed phenomena by attributes. Finally, the top of the pyramid is where preliminary statements of correlation are proposed and investigated further. Ascending the pyramid is analogous to zooming out, or entering into the analysis phase established by Kimmel (2005). Operating within an interface that offers fluidity between the measured phenomena (observed during experimentation) and the hypotheses (proposed during requirements generation) points to a Model-Based Systems Engineering (MBSE) atmosphere.

Leydesdorff & Meyer (2006) propose the use of multiple axes in their triple helix model, that considers additional perspectives, which enables the specification of relevant categories for observation in terms of expectations. Leydesdorff & Meyer explain how a diffusion dynamics parameter, pulled by an economic system’s thirst for profit, is responsible for distributing systems into other domains, sometimes to their own demise. An example is given on a co-evolution that initially exists between the knowledge-production function and local Italian markets. Once an innovation travels a certain distance along its trajectory, it dissolves into a

new stage of challenges and opportunities. In this paper, an outcome to a collaborative situation is a 3D trajectory showing signs of variation and sensitivity with respect to an orthogonal frame representing industry, academia, and government relations. This tri-lateral relationship between industry, academia, and government is a useful insight to explore further in an MBSE atmosphere targeting the ground vehicle robotics industrial base.

Blackburn, Mazzuchi, & Sarkani (2012) held that the Quality by Design (QbD) approach, when coupled with TRIZ (Russian inventive problem solving) principles, addressed more physical and technical contradictions with inventive solution, thus thwarting the psychological inertia (PI) associated with engineers stepping outside their background to observe useful patterns. The authors deemed that aligning the 39 abstracted engineering parameters with the 40 already successful inventive principles eliminated system contradictions better than the idea generation heuristics derived by trial and error alone. Observing and applying patterns reuses the expertise of experienced designers and is considered to be a low investment with high potential returns – therefore, TRIZ is considered to be a heuristic approach to innovation with applicability to manufacturing systems and supply chains. Traditional approaches such as Quality by Inspection (QbI) and Quality by Testing (QbT), popular in the pharmaceutical industry, were contrasted in the paper under the format of trade studies. TRIZ, which taps into the diversity gathered from working in different industries, is an effective approach to complementing defense competence with automotive industry experience, for example. Process Analytical Technology (PAT) is another emerging system for designing, analyzing, and controlling manufacturing through timely measurements and is used as one of the baselines in the trade studies. Some of the various methods for alternative rankings and across-pattern comparisons were explained which include

affinity ranking, ratio method, tradeoff methods, swing weights, rank-order centroid techniques, the analytic hierarchy process (AHP), balance beam, and lottery questions. Two tradeoff metrics were used in the paper involving quantities like the percent of contradictions that have at least one high-ranked conceptual solution and average ranking of all conceptual solutions within each alternative. Alternatives that address more conflicts with effective inventive solutions suggest that better system performance will be achieved. Finally, a sensitivity analysis follows that affinitizes inventive solutions in logical categories and counts the frequency of occurrences, while differentiating the degree of contradiction resolution within each category. Engineering Design, PAT, and Product Development were the top three inventive solutions in the affinity ranking and were depicted in a visual analytic that resembles a Pareto chart with stacked vertical bars representing the count of high, medium, and low ranks.

Fey (2012) instructed that the act of zooming in and out amongst different levels of analysis helps remind TRIZ practitioners that their problems, and thus their solutions, are probably not unique to their industry. Problem spaces can manifest themselves differently under varying zoom levels, such as a curve resembling a segment, when under high magnification. Visual models often lead to mathematical models which lead back to geometry. In fact, TRIZ breakthroughs are commonly depicted as geometric and mathematic representations dwelling outside of some familiar domain represented as a geodesic, in and of itself, and apply to topics like supply chain streamlining (pp. 8-10). In fact, the evolution of successful systems proceeds along universal vectors, or laws of evolution. Fey presented visual analytics like System Conflict Diagrams, technology improvement S-curves, and Customer-Satisfaction Models. These depictions are not unlike the paradigm shift S-curve of Christensen (2005) and the Kano

Model reviewed by Chowdhury (2002, p. 90). TRIZ leverages cognitive splits, similar to Lean Six Sigma (LSS) and Kepner Tregoe (KT) practices, including primary and auxiliary functions, as well as requirement conflicts and distinctions. Fey offered that some visual representations are more thought provoking than others, which suggests opportunities for subsequent research.

Tian, Zhong, Xiao, Du, and Yang studied the integration of axiomatic design (AD) and TRIZ for the conceptual design of heating and drying equipment in a bitumen reproduction device (2010). The main premise of TRIZ was presented, along with AD, described as a systematic problem solving tool based on the application of two axioms: 1) the independence axiom and 2) the information axiom. The independence axiom states that the functional requirements (FRs) of the problem should be independent of one another, whereas the information axiom states that the better solution has minimal information content. The four domains of AD are: 1) the customer domain, 2) the function domain, 3) the physical domain, and 4) the process domain. Solutions are generated by mapping requirements of one domain against a set of characteristic parameters in an adjacent domain. A series of iterations between FRs and design parameters (DPs) is advised. The three categories of design manifest themselves into matrix patterns that are visually recognizable between uncoupled, decoupled, and coupled decrees. The authors presented the integrated model in six steps, with an accompanying flowchart, including: 1) requirements transformation, using Quality Function Deployment (QFD), 2) construction of FRs and DPs (using AD), 3) design matrix assessment (in terms of coupling), 4) coupling resolution (using TRIZ), 5) design matrix reassessment, and 6) detailed design. Finally, heating and drying equipment design alternatives were represented as FR and DP matrices exhibiting decoupled and uncoupled behavior. Using TRIZ to transform the technological contradictions, design

alternatives were refined and compared in terms of their DPs, proving that the integrated model enabled the decision making process, as predicted.

Mehta & Cooper (2011) held that design is essentially a process of generating knowledge about how to build new systems and results in structured libraries of design projects and risk assessments. Using an integrated circuit (IC) example to represent a textbook platform-based design (PBD), the authors explained how each IC layer is developed with reuse as one of the objectives. With the advent of cyber-physical systems (CPSs), embedded systems PBD approaches consider physical elements as devices that merely provide feedback to software. Therefore, CPSs have much more flexibility around definition of platform layers which leads to variation in hierarchical representation of systems across design teams and, thus, reduces reusability of platforms. Each layer means something different in each instantiation of the system. In fact, platforms are thought of as libraries of design projects at different levels of a systems configuration hierarchy. The authors offered that the key to the success of PBD is the taxonomies of the platforms. A ground vehicle (GV) example was constructed from previous instantiations, showing taxonomies like: hull/frame body/cab, ground interface, powerpack, drive train, system survivability, and lethality. Although software developers try to define and control all interactions between modules and objects, many interactions remain unknown at the time of design and are only discovered during testing or deployment. Therefore, interactions must be captured upstream, during risk assessments, which are meant to identify the risks of system failure. All in all, the knowledge transfer across design teams that is possible with a hierarchical PBD (and accompanying risk assessment) has a greater benefit to more complex systems and those with longer product development cycles.

Wang & Dunston (2006) agree with Ellis, Gibbs, & Rein (1991) in that groupware entails computer-based systems that support groups of people engaged in a common task and interacting in a shared environment. Wang and Dunston distinguish between an augmented reality (AR) system of collaboration and a teleoperation class of systems. Collaborative AR occurs when the real environment is augmented by another user without solely relying on previously stored information. Allowing users to be aware of the activities of other users, aside from human-human communication services, was one of the themes of the paper. The authors indicated that AR has more applicability in the construction domain, due to large distances between mobile work crews, but this characteristic is common to any other support team developing and maintaining systems in the Army. Categories of AR systems are explored which include number of users, degree of mobility, and space (proximity of users to one another). In addition, some noted AR examples for each of the categorical combinations are given. Wang & Dunston explain some of the issues associated with multi-user, face-to-face systems, including social distractions (non-task-related topics) and model disorientation amongst distributed users, following the model navigation of another distributed user. On the other hand, virtual space systems that witness a small gain in efficiency (due to a decrease in social distraction) experience difficulties in voice transmission and added effort to feedback information. Wang & Dunston (2009) also found that frustration levels and conceptual performance were significantly improved (up to 41.4%), during experiments deploying a range of Mixed Realities (MR), competing against a range of Augmented Reality (AR) and Augmented Virtuality (AV).

Ries, Lance, and Sajda described brain-computer interaction technologies (BCITs) that enable large datasets to be accurately interrogated by analysts in a short amount of time (2011). Ries, Lance and Sajda recognized the speed and precision of the human visual system to pick up minute distinctions in various stimuli and establish SA. Using measured neural signal data, such as electroencephalography (EEG), experiments were conducted to identify when an observer detects a sought after pattern or target. Integrating a Cortically-Coupled Computer Vision (C3V) system with a rapid serial visual presentation paradigm (RSVP), three different methods were trialed: 1) computer first, 2) human first, and 3) a tightly-coupled method, where the P300 RSVP task, as well as the computer vision ran in an iterative fashion to aid in target detection. The tightly-coupled method showed promising results in that over four times more targets were detected within the first 20 minutes, over the other baseline methods.

Ortland, R. J., Bissonnette, L. A., and Miller, D. R. (2010) applied data mining and analysis to proactively assess the wear of military ground vehicle components. The study involved the trending and graphic display of equipment demand information over extended periods of time. Equipment deemed most critical to maintenance was given priority in the analysis. Data was gathered from information sources like the Integrated Logistics Analysis Program (ILAP), the Operating and Support Management Information System (OSMIS), and the Army Materiel Systems Analysis Agency (AMSAA). With the ability to assess entire platforms for part data trends, the authors uncovered strategic trends that were not visible when looked at in piecemeal. High-volume, low-price parts like seals and bearings were found to represent significant total cost to platforms. This fact, coupled with the existence of instances of part commonality between platforms gave rise to the same parts showing up on multiple lists. The data review

process made extensive use of charts, graphs, and trend analyses. Specifically, the graphic representation of data showed particular value when distinguishing between South West Asia (SWA) and non-SWA patterns. Feeding the results of the analysis into Failure Mode Effects Analysis (FMEA) initiatives concluded the study.

Estefan defined methodology as the overall application of: 1) the “what” of processes, 2) the “how” of methods, and 3) the corresponding tools and meta models that aid in process and method execution and development. Estefan surveyed different levels of MBSE analysis abstraction, as well as the connotations of model-driven system design (MDSD), including state analysis (SA). Through use of state variables, transient states are defined as momentary conditions of an evolving system and contain goals and constraints. State estimation is kept separate from state control, in order to isolate an objective assessment of a particular system. Estefan also depicts a visual analytic called an onion model that uses layers of SE activities to aid in cognition and solution exploration (2007, pp. 28-37). Distinctions between SE process standards DoD-MIL-STD 499, DoD-MIL-STD 499B, IEEE 1220, ISO/IEC 15288:2002, ISO/IEC 19760, NASA NPR 7123.1A, and ANSI/EIA 632 were also depicted.

According to Dorf & Bishop (2011), the concept of a system state, and corresponding state variables, is useful in analyzing social and economic systems (p. 187). The state variables describe the present configuration of a system and can be used to determine the future response, given the excitation inputs and the equations describing the dynamics (p. 185). Visual analytics such as Mason’s signal-flow graphs and block diagram models have proven to aid in

understanding and foster innovation. Therefore, state variables and state analysis are systems modeling points of view that require further attention (Estefan, 2007, p. 34).

Samson & Peterson (2010) presented an application of a Design Structure Matrix (DSM) that enables the modeling, visualization, and analyses of any system. DSM is a matrix-based system modeling methodology that may be applied to the three critical domains of the design and development of systems: 1) product, 2) process, and 3) organization. Each domain has different ways to approach the populated matrices that follow. DSM can be related to other square-based matrix methods or even non-matrix-based methods, like systems of equations. After decomposing products, processes, or organizations, the relationship or pattern of interactions between decomposed elements ends up defining the architecture. There are two types of DSMs: 1) temporal (time-based relationships between elements) and 2) static (relationships that are not time-based). The general DSM modeling approach consists of the following steps: 1) define the system boundary, 2) describe important interfaces, 3) decompose the system into simpler elements, 4) define the characteristics of the elements, 5) characterize the element interactions, and 6) analyze the system architecture. In the process domain, for example, the result is a visual analytic that offers insight into iterative information flows through tasks, depicted as x's in a square matrix with a boundary along the diagonal, where the tasks associated with column headings transfer information to those tasks associated with row headings. Conversely, the tasks associated with row headings require information from those tasks associated with column headings. Depending on how the x's are clustered, gives a visual indication of how they interact and how they might be resequenced. Overall, a process DSM can prove to be a framework for knowledge management. Within the product domain the interactions get classified and

quantified prior to clustering like-patterns together. Analysis of the system architecture in this manner identifies functional modules and distributed subsystems and can generate alternative views on system architecture. Organizational decomposition, on the other hand, requires an understanding of the elements and their relationships. The authors stated that the greatest leverage in organizational architecting lies between the relationships. In fact, an organization's inability to integrate team structures can lead to information overload. The resulting DSM for organizations offers single-picture visibility on the communication frequency amongst teams.

Pilemalm, Hallberg, Sparf, and Niclason (2012) reported on their experiences of model-based development, using case studies from the Swedish Armed Forces. The top identified challenges in the model-based development and implementation processes were found to be common organizational and system development related problems like: change management, team participation, and execution of requirements engineering. The authors state that there is a need to study aspects of model-based development and implementation from the perspectives of organizations, practitioners, and system stakeholders. The basis for model-based development includes: 1) development processes, 2) meta models, 3) relations and transformations. Although models can be paper-based, computer-based, 1-dimensional or multi-dimensional, manually or automatically generated, this study refers to computer models, generated manually, using COTS tools feeding an architectural framework. The Ministry of Defense Architectural Framework (MODAF), North Atlantic Treaty Organization Architectural Framework (NAF), Department of Defense Architectural Framework (DODAF), and The Open Group Architecture Framework (TOGAF) were discussed as well as a unified profile, called (UPDM), attempts to create a standard Unified Modeling Language (UML) profile between architectures. UPDM shares

concepts with SysML and can be considered as a meta model that allows non-technical experts to participate in strategic decisions, where a full, system stakeholder perspective is often missing. The authors state that the application of models to the development of capabilities constitutes pioneering work. The four projects exemplified in the study included: 1) business management software, 2) future command and control systems, 3) capabilities modeling, and 4) requirements for equipment in an international peace operation. A MODAF visual analytic resembling a Swim Lane Diagram was presented, illustrating how human and technical functions support missions. Midway, the authors recommended protocols for conducting case studies while explaining their rationale for conducting interviews. The interviews resulted in three themes, including: 1) process development, 2) organizational implementation, and 3) organizational implications. These themes were further subdivided into several layers, each with their own lessons learned. Some of the lessons learned communicated in the study were: 1) model-based atmospheres help identify the task redundancies and pedagogical perspectives of different organizations, 2) model-based protocols promote a universal language and architecture with which to work, 3) model-based protocols help enforce critical information sharing upstream when the success of projects is most volatile, 4) having a model-based framework helps identify early on the stakeholder representatives who were lacking sufficient domain knowledge to perform tasks, and 5) the framework enforces systems requirements to be drawn from the emerging models. For model-based development to be successfully implemented, more resources need to be allocated toward information management, marketing, and education, as these areas required more than was initially expected (especially in the initial phases). Several projects also reported that many stakeholder representatives did not represent the real users and did not carry out their tasks as organizational integrators. In addition, the survey respondents

described that the organizational implementation process encompassed more obstacles than the developmental phases. The modeling of the processes was reported as creating an organizational memory, in addition to providing a fundamental overview and clarity of organizational vision, missions, and individual responsibilities, which were noted as difficult to find. In fact, the lack of connection between overall goals, strategies, and models, along with a lack of purpose, have led to uncertainty in terms of what should be modeled. Premodeling, or preliminary information gathering, required more attention and should not be deemed as unproblematic. Surprisingly, most of the obstacles experienced do not even relate to the model-based processes, but rather manifest themselves as general systems and organizational development problems – therefore, the lines of demarcation between the two disciplines are blurred. The study confirmed that these obstacles were deemed more challenging than the more technical modeling work and the models themselves. Although the acceptance level for model-based approaches was observed as low, the respondents speculated that a model-based atmosphere will lead to a more functioning and structured organization, where an elimination of double work will lead to higher profits. Unfortunately, none of the reported projects performed a risk analysis on the model-based way of working. In summary, the authors state that a solid combination of scientific research and practical experience is needed to carry out the inherent complexity of a model-based development approach.

Mendonza & Fitch (2011) proposed mapping all SE knowledge to a database of object classes and subclasses (within appropriate hierarchies), while leveraging the evolution of attributes and relationships, as opposed to relying on view-based artifacts (e.g. DODAF) that typically fall victim to clerical degradation and unnecessary variance. Distinguishing Object-Based Systems

Engineering (OBSE) from that of MBSE, Mendonza & Fitch agreed that only OBSE truly captures the essential elements (e.g. objects, attributes, relationships) of SE, fully noting that information architecture may vary for different domains. An OBSE focus brings to light benefits which include: 1) artifact reproduction through concatenation of object attributes and relationships, 2) a shift towards object quality reviews (as opposed to document reviews), and 3) the capability to proactively analyze diagrams and tables. Roadblocks to the realization of OBSE include: 1) process inertia, 2) tool limitations, 3) stovepiped cultures, and 4) the interaction between tight budgets and fear of scope creep. Differences between the connotations of terms like “methodologies” versus “principles”, as well as “architectures” versus “foundations” were also discussed. Similar to coupling theory in AD, the traceability between SE questions and answers was presented in the form of an N-Squared Diagram that reveals interactions between diagonal nodes representing: 1) Statement of Work (SOW), 2) Work Breakdown Structure (WBS), 3) Decisions, 4) Architecture, 5) Requirements, and 6) Tests. Using the SE Vee-model as a methods engine, a decision-to-requirement traceability was researched. Offering that each object class evolves through a series of states and that system states activate and deactivate functions, the authors offered that object-level versioning captures states as attribute and relationship differentials. Capturing the logic behind the knowledge derivation is of high importance and uncertainty is to be reduced through investments in stochastic M&S that exposes instances of knowledge in the form of single instances of objects viewed through multiple lenses. Studying the attributes of the links between objects, sensitivity analysis can be performed, using simulation models. In summary, the authors state that a class-based model encourages efficient, focused brainstorming, just as a shared information model fosters collaboration.

Mendonza & Fitch (2012) stated that effective decision management (DM) is much more than a mere Analysis of Alternatives (AoA) and is comprised of three elements: 1) decision patterns through which subject matter experts influence designs with their unique knowledge, 2) a DM methods engine, and 3) a decision-centric information model. DM can be the key enabler for accelerating the benefits of the SE discipline to new industries and domains. A decision pattern was defined as a hierarchical model of the problem domain in which each decision represents a fundamental question/issue that demands an answer/solution. The decision pattern forms a Decision Breakdown Structure (DBS) which contains nodes like “state model” and “support”, among others. In the DBS, three types of decision are included: 1) single answer decisions, 2) multiple answer decisions, and 3) multi-part answer decisions. Every system is said to have a functional model and needs a bounded mission scope from which its operational requirements are derived. A rapid reverse engineering exercise, known as a Decision Blitz, was discussed that maps existing systems to decision patterns. The authors emphasized that DM is scalable, due to it being domain-independent. Specifically, for the decision-centric information model, the object classes and their relationships have ties to human thinking and cause & effect patterns, not based on a specific type of system, industry, or use case. Information visualization and the importance of proactive identification and prioritization of decisions was also stressed. Overall, the challenges of deploying a traditional SE framework, utilizing MBSE, were covered. Capturing the system model, instead of the thinking model, was cautioned. In summary, the authors felt that a tool-driven SE outreach strategy would work best when it is built around a specific tool that already has gained traction among engineers. Also, cross-pollinating SE tools to other

groups could be accelerated if SE champions from other industries have already infiltrated the target domain.

Mendonza (2012) presented the TARDEC Advanced Systems Engineering Capability (ASEC) which is an integrated SE knowledge creation and capture framework built on: a decision-centric method, high quality data visualizations, data traceability, real-time collaboration, and knowledge pattern leverage. The ASEC framework consists of three parts: 1) Problem Space (Inputs), 2) Innovation/Analysis Space, and 3) Solutions Space (Outputs). Mendonza emphasizes the utility of the meta model containing the full system information. The five models from which SE knowledge is created and captured include: 1) SE Vee Model, 2) M&S Models, 3) Architecture Model (SysML), 4) Lifecycle Models (e.g. sustainability), and 5) Roadmap Model. Some of the benefits of ASEC include: improved ability to visualize choices, decision patterns are highlighted that extend subject matter expert influence, and a traceability to upstream decisions from which requirements have been derived. Presenting and displaying object-based SE knowledge pertaining to multi-dimensional systems trade space allows for fast comprehension and decision making. With ASEC, alternatives reflecting quantitative and qualitative data are visually stacked, between the threshold and objective criteria values, before being discriminated based on scores. After some collaboration, it is suspected that Mendonza's ASEC will be the target framework with which to integrate the IB modeling application of this research proposal. After all, within ASEC, the decision model for a system provides the integration point for all other system models (Mendonza, personal communication, January 25, 2013). Woody & Hoff (2010) offer an analogous middleware solution to managing independently developed applications that provide SA data to Warfighters. What is deemed as

an Application Framework, an overarching infrastructure orchestrates coexisting applications like: 1) command and control, 2) sensor control, 3) presentation, and 4) communication that can be selectively deployed based on mission parameters and objectives.

Taylor (1990, pp. 123-125) taught that the more that models are used for multiple applications in an object database, the more the applications lose their stovepiped identities, due to integration of data. This results in the refinement of shared models which enables the simulation of various company operations.

COTS supply chain management software tools like: ProModel, Supply Chain Sherpa, Supply Chain Guru, Supply Solver, SDI Industry Pro, and IBM Supply Chain Analyzer have varying utility, but still do not provide the holistic view and strategic sustainment analysis capability that TARDEC needs to proactively assess military sustainment support strategies. Moreover, acquiring new COTS tools instead of fully utilizing TARDEC's existing licenses of COTS software is not recommended in this research proposal. COTS capability already exists to visualize multiple system requirements, behavior, structure, and parametrics, while managing mission resource allocation amongst an enterprise of organizations (Friedenthal, 2012, p. 11). Considering that energy and resource distribution follow definite paths which can be analyzed by means of geometric construction, 3D models can inspire more what-if analysis capability through the interactive deployment of visual analytics (Taylor, 1990, p. 80; Schneider, 1994, p. 78). Many times, innovative adaptations of COTS solutions meet, or exceed, system expectations. For example, although typically only thought of in the product design genre, it is suspected that Pro Engineer (Pro/E) has the capability and availability to bring to light many of

the multiple dimensions and layers of the sustainment IB. Used in conjunction with other COTS tools encouraged by the DEMs curriculum (e.g. Arena, Minitab, Octave, LabVIEW, Maple), M&S scenarios can be economically tested in a benign, proactive environment orchestrated by SysML, which is recommended by INCOSE. MajicDraw, for example, is one of the INCOSE-recommended COTS tools that can be used to quickly exercise SysML to frame any M&S efforts being conducted. Specifically, by populating some of the primary SysML diagrams with structured links to models from other domains, the untapped community of IB stakeholders will be forced to calibrate their everyday language and activities, filling TACOM IB analysis voids, while simultaneously thwarting unconscious redundancy.

Strategic analysis involves zooming out from the current view. A model that has the capability to toggle back and forth between high level perspectives and low level perspectives is an asset to a strategic analyst (Kleijnen, 2005; Kimmel, 2005; Patria 2010; Bean 2011). For example, the macro view of a supply chain is its parent IB. Kimmel (2005) explained how the macro phase, itself, is to be thought of as the analysis phase. From this analogy, it can be concluded that IB analysis delves more into the strategic planning discipline than does mere supply chain management. Kimmel also establishes that the most detailed micro view is the code of the modeling language itself. It is important to acknowledge the precautions of relying solely on the modeling language code, however (Bell, 2004; Booch, 2004). Sole reliance on the modeling language code ignores the strategic side of what should be a value-added modeling approach. Consciously exploiting the strategic lens of an IB model helps to understand the problem space. Capturing classes and relationships, as the problem space is being studied, is advised in the literature. As the details of the model are characterized, moving from a macro understanding to a

more detailed micro understanding allows the community to elaborate on a solution design. At this point, reviewing class diagrams and adding operations and attributes is advised. Operations, behaviors, and methods all refer to the same thing, although UML generalists use the word “operation”, but when coding, the word “method” is most popular (Kimmel, 2005).

In conclusion, the specification, analysis, design, and verification of the entire sustainment IB, as a system, is a multi-dimensional entity. Acknowledging the influence of IT, missions involving IB data access and strategic decision making can be considered as use cases in a systems design interface where various agencies can “explore the behavior of many objects across a use case” (Kimmel, 2005). This kind of lateral thinking facilitates SA and enables pattern recognition (Dew, 2006). Once patterns are exposed, innovation can follow. TRIZ innovation is often thought to be a novel adaptation of ancient physics and existing geometry, in order to resolve the secondary problems, or contradictions, unveiled during systems analysis (Clarke, 2005; Blackburn, Mazzuchi, Sarkani, 2012, p. 357). In other words, trend recognition is the oftentimes considered to be the seed of the fruit of innovation. Analysis, itself, often follows the S-curve of technology improvement as analysts begin with alphanumeric lists, then evolve to 2D visual analytics, then interact with a distributed workforce using 3D collaborative models (Carnegie, 1944, pp. 555-556; Fey, 2012). This mind-set, coupled with the decision to use the momentum of established COTS tools upholds Ashton Carter’s charge to “do more without more” (2010).

Research Proposal

To develop a solution to the problem (stated on p. 9), the following research goals are proposed:

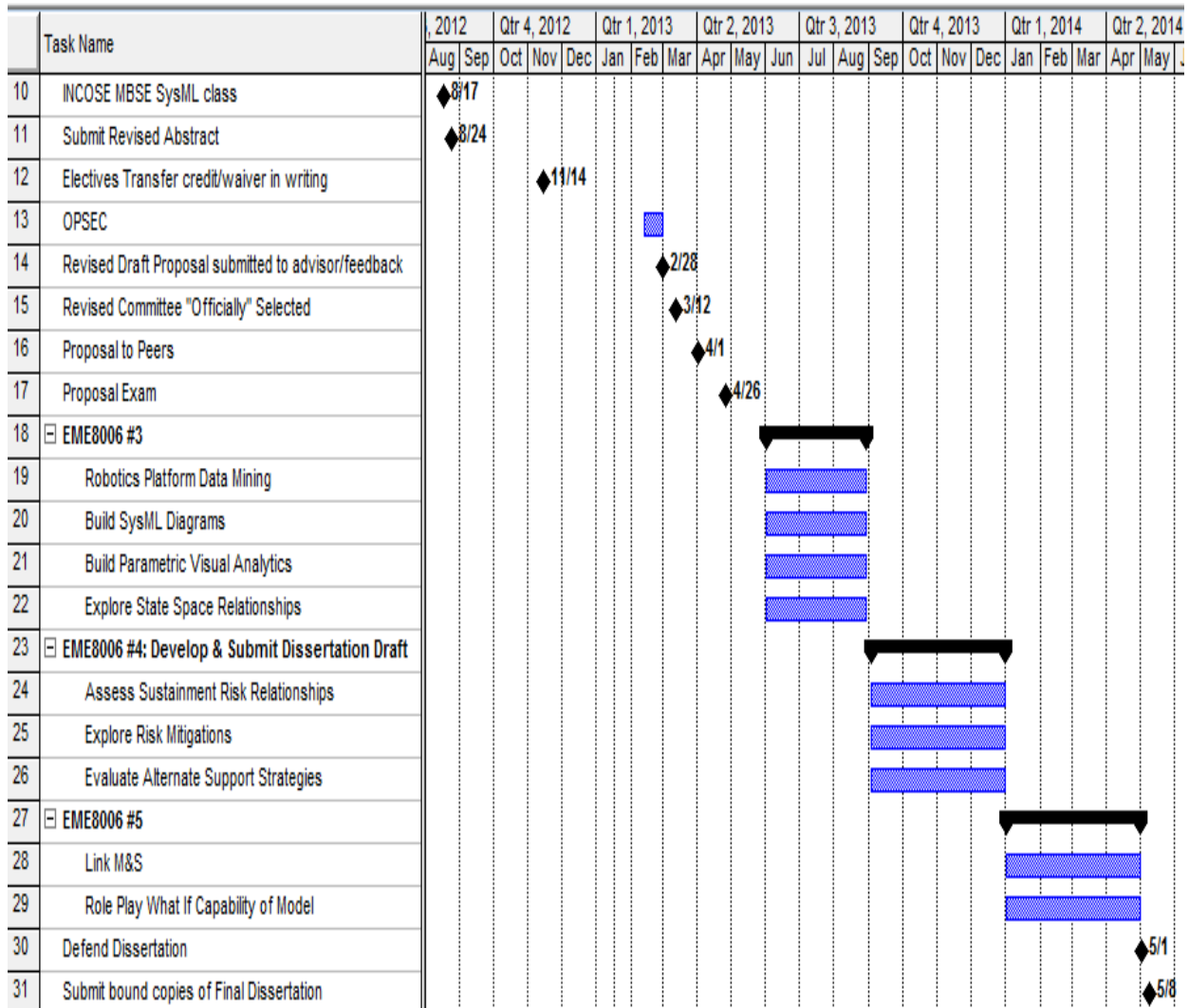


Figure 10: DEMS research Gantt Chart

The mathematical basis for the proposed research is expected to center around the general form of state-space representation which includes:

State differential equations of form:

$$\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu} \quad (\text{Eq. 1})$$

and Output equations of form:

$$\mathbf{y} = \mathbf{Cx} + \mathbf{Du} \quad (\text{Eq. 2})$$

where Equation 1 can be expanded to:

$$\frac{d}{dt} \begin{bmatrix} x1 \\ x2 \\ xn \end{bmatrix} = \begin{bmatrix} a11 & a12 & a1n \\ a21 & a22 & a2n \\ an1 & an2 & ann \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ xn \end{bmatrix} + \begin{bmatrix} b11 & b1m \\ bn1 & bnm \end{bmatrix} \begin{bmatrix} u1 \\ um \end{bmatrix} \quad (\text{Eq. 3})$$

Any supporting visual analytics that aid in understanding or foster innovation will be explored.

Both mathematical and visual analytic models, portrayed in a synthetic environment, will be

linked to a parent, MBSE framework to heighten situational awareness and demonstrate

improved resource continuity. It is suspected that IB and sustainment risks pertaining to the Ground Vehicle Robotics domain will be analogous to the excitation of transient state space input signals. Typical systems offer several choices of state variable sets that describe the dynamics of systems, but state variable sets which can be scrutinized by robust measurement systems are preferred (Dorf & Bishop, 2011, p.187).

Upon completion of this research, a cost avoidance is anticipated, due to a more focused allocation of human resources towards IB analysis. This, along with offering a broader understanding of sustainment risk amongst Ground Vehicle Robotics, promises a new facet of M&S within TARDEC. Given that a proportion of equipment applications historically become reactive, Diminishing Manufacturing Sources and Material Shortages (DMSMS) issues, proper risk management will reduce the population of DMSMS candidates.

Business Case

Developing awareness of DMSMS indicators is the first stage of IB risk management.

Therefore, the business case paradigm for this research proposal could be viewed as the avoidance of cost and equipment readiness decline associated with a series of DMSMS cases that have a probability of occurring and are treated as a failure of sustainment support (see Equation 4 below)

$$\mathbf{C} \sim \sum_{i=1}^n P(\mathbf{D} + \boldsymbol{\varphi}(t)) \quad (\text{Eq. 4})$$

Where C is the total burden to the platform, n is the number of DMSMS cases in a given time frame, P is the probability function, D is the cost of the DMSMS case, and φ is a penalty function that burdens a platform when they reside below equipment readiness thresholds for a given time frame.

The anticipated investment to proliferate an MBSE solution that encompasses sufficient IB analysis is expected to follow a modified annuity series cash flow diagram of form:

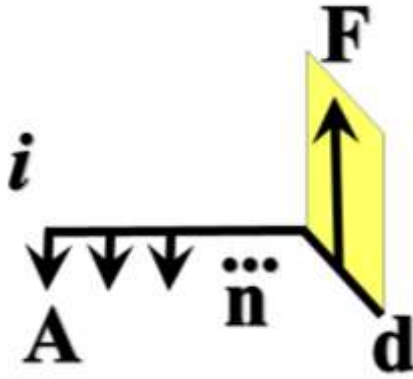


Figure 11: Cash Flow Diagram depicting benefit of proposed research

which equates to a breakeven equilibrium of:

$$F = d * A \left[\frac{(1+i)^n - 1}{i} \right] \quad (\text{Eq. 5})$$

where F is the benefit, or the avoided cost increment (i.e. markup) per mitigation decision, A is the cost per head, or the fraction of time each analyst spends on maintaining the proposed IB model, n is the time period between mitigation decisions, i is the interest rate of opportunity cost, and d is the depth of how many analysts presently manage equipment for the command. A rough estimate of the burden on human capital, A , is shown in Appendix C, with d set at 200 analysts. In which case the overhead cost of human capital is fixed at $A*d$, Newman (1996, p. 166) simply recommends to maximize the equivalent uniform annual benefits (EUABs). Note that the EUABs manifest themselves as an avoided markup, F , in Figure 10. Both, the avoided markup, F , and the depth of analysts, d , are presented in a third dimension to illustrate the cost-to-benefit tie to the variable pool of analysts contributing to the IB model's upkeep. In other words, each analyst will be responsible for maintaining his/her particular aspect of the IB (for which they already manage equipment).

With respect to Equation 4, the cost, D , of a real DMSMS case can be demonstrated in the following example where a reactive demand arises for fuel lines that are out of production. The total anticipated, life cycle demand calls for \$7,552,000 of fuel lines (3200 lines * 8 lines per fuel pump * 2 fuel pump variants per vehicle) at \$147.50 per line. Approximately one-third of the quoted piece price can be attributed to a markup that is the result of a bounded support strategy. Market constraints like this that are identified through IB M&S (and proactively mitigated) can equate to a cost avoidance, F , of \$2,517,333 (33% of \$7,552,000). Therefore, substituting $3*F$ in for D , in Equation 4, yields:

$$C \sim \sum_{i=1}^n P(3 * \left[d * A \left[\frac{(1+i)^n - 1}{i} \right] \right] + \varphi(t)) \quad (\text{Eq. 6})$$

Committee Approval of Research Proposal

Signature

Date

Dr. Alwerfalli, Academic Advisor

Dr. Overholt, Industrial Advisor

Dr. Ali, Committee Member

Dr. Riedel, Committee Member

Dr. Bindschadler, Committee Member

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Appendix A

Cambridge University Press

Tank Automotive Research Development and Engineering Center

Assistant Secretary of the Army for Acquisition, Logistics, and Technology

Swiss Federal Institute of Technology

University of Illinois

Journal of Supply Chain Management (ISM)

Purchasing Management Association of Canada (PMAC)

National Association of Purchasing Agents (NAPA)

VVT Technical Research Centre of Finland

National Institute of Governmental Purchasing (NIGP)

Rand Corporation Publications

American Society for Quality (ASQ)

Association for Computing Machinery (QUEUE)

National Science Foundation (NSF)

Defense Standardization Program Journal

UNCLASSIFIED

Production & Inventory Management (P&IM) Journal - Association for Operations Management (APICS)

Journal of Engineering for Industry

International Journal of Production Research (IJPR)

Social Science Information

Council of Supply Chain Management Professionals (CSCMP)

United Nations Conference on Trade and Development (UNCTAD)

Journal of Computational Physics

Winter Simulation Conference (WSC)

Computer-Aided Design

Army Sustainment (Army Logistician)

International Journal of Systems Science

Parameters

Association for Unmanned Vehicle Systems International (AUVSI)

Research Policy

Industrial Robot: an International Journal

Armed Forces & Society

International Journal of Production and Economics

European Journal of Operational Research

International Journal of Computer Applications

Journal of Business Logistics

Journal of Operations Management (JOM)

International Test and Evaluation Association (ITEA)

International Journal of Robotics Research

Journal of Robotics Association of Japan

IEEE Robotics and Automation Society

Journal of Automotive Engineering

International Federation of Purchasing and Supply Chain Management (IFPSM)

Journal of Intelligent and Fuzzy Systems

International Journal of Robotics and Automation

International Symposium on Robotics and Manufacturing

Center for Advanced Purchasing Studies (CAPS)

International Journal of Technology Management (IJTM)

AMR Research, Inc.

Voluntary Inter-Industry Commerce Standards Organization (VIICSO)

International Journal of Approximate Reasoning

International Journal of Engineering Applications of Artificial Intelligence

International Conference on Intelligent Robotics and Systems (IEEE/RSJ)

Journal of Systems Engineering (INCOSE)

Journal of Intelligent Manufacturing

Journal of Manufacturing Technology Management (JMTM)

Pacific Conference on Manufacturing (PCM)

Systems Engineering Society of Australia (SESA)

Journal of Strategic Information Systems

International Purchasing and Supply Education and Research Association (IPSERA)

MIT Press Journals: Teleoperators and Virtual Environments

Journal of Intelligent Automation and Soft Computing (AutoSoft)

Intelligent Autonomous Systems Society

IEEE International Conference on Fuzzy Systems

Association of Autonomous Astronauts

World Trade Organization (WTO)

Institute for Operations Research and the Management Sciences (INFORMS)

Joint International Conference on Computing and Decision Making in Civil and Building Engineering

International Journal of Intelligent Systems

IEEE/ASME Transactions on Mechatronics

Supply Chain Council (SCC)

International Journal of Intelligent Control and Systems

Journal of Autonomous Agents and Multi Agent Systems

Journal of Battlefield Technology

International Symposium on Mixed and Augmented Reality

Nielsen Norman Group

EECOMS

Pixel - New Perspectives in Science Education

Journal of Automation, Mobile Robotics & Intelligent Systems

Logistics and Supply Chain Management Society (ISCMS)

International Journal of CAD/CAM (IJCC)

International Journal of Vehicle Autonomous Systems

Journal of Applied Artificial Intelligence

International Research Study of Public Procurement (IRSPP)

International Conference on Creating, Connecting, and Collaborating through Computing

International Journal of Advanced Robotic Systems

International Journal of Intelligent Information Technologies

International Journal of Simulation & Process Modeling

Journal of Field Robotics

Journal of Intelligent Transportation Systems

International Journal of Marine Navigation and Safety of Sea Transportation (TRANSNAV)

International Journal of Autonomous and Adaptive Communications

International Journal of Intelligent Computing and Cybernetics

Journal of Operations and Supply Chain Management (JOSCM)

International Journal of Social Inquiry (IJSI)

International Journal of Intelligent Systems and Applications

Ground Vehicle Systems Engineering Technology Symposium

Carnegie Mellon Univ. Center for Collaboration Science and Applications Colloquium Talks

International Journal of Intelligent Computing

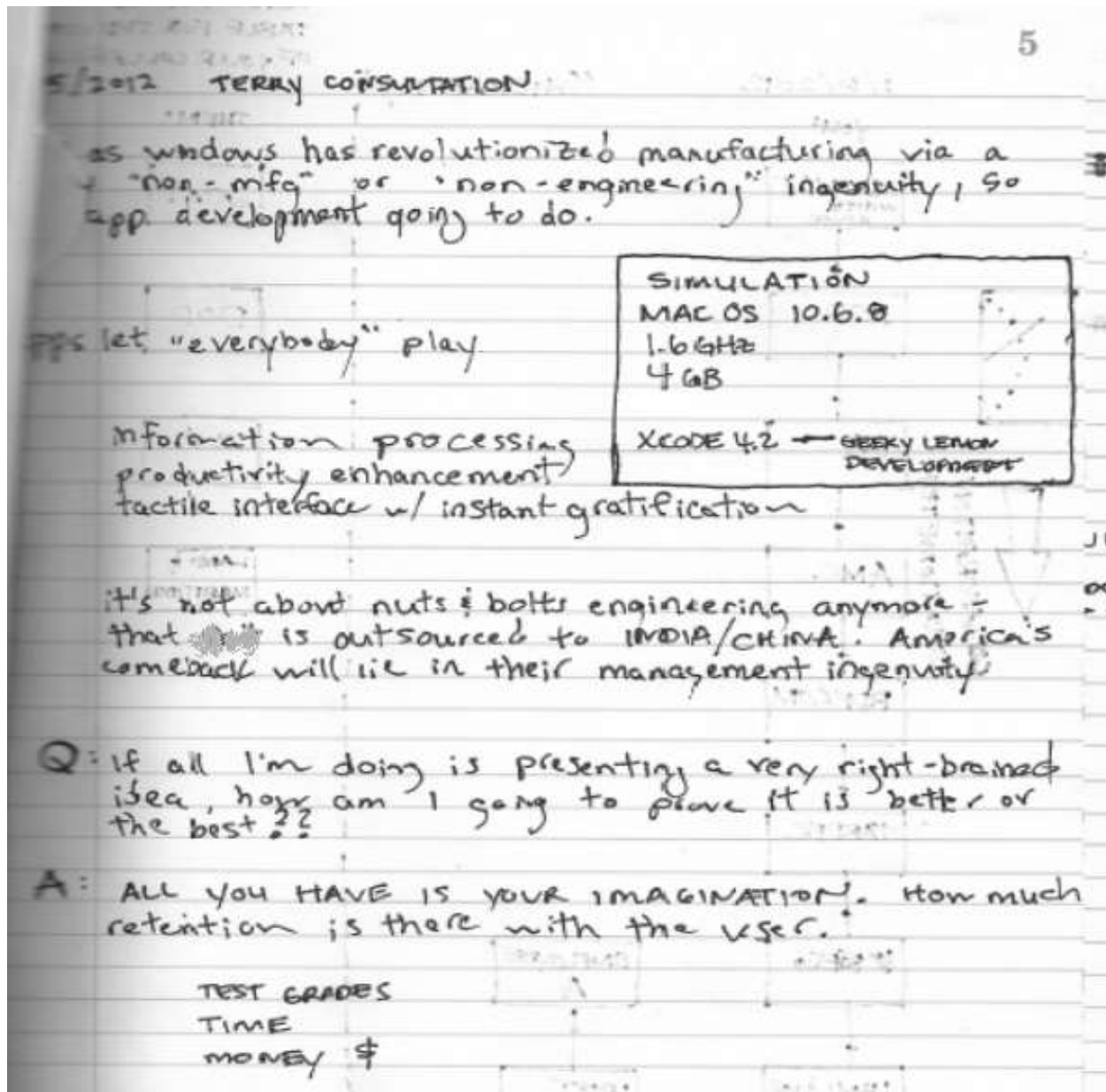
International Society of Intelligent Unmanned Systems

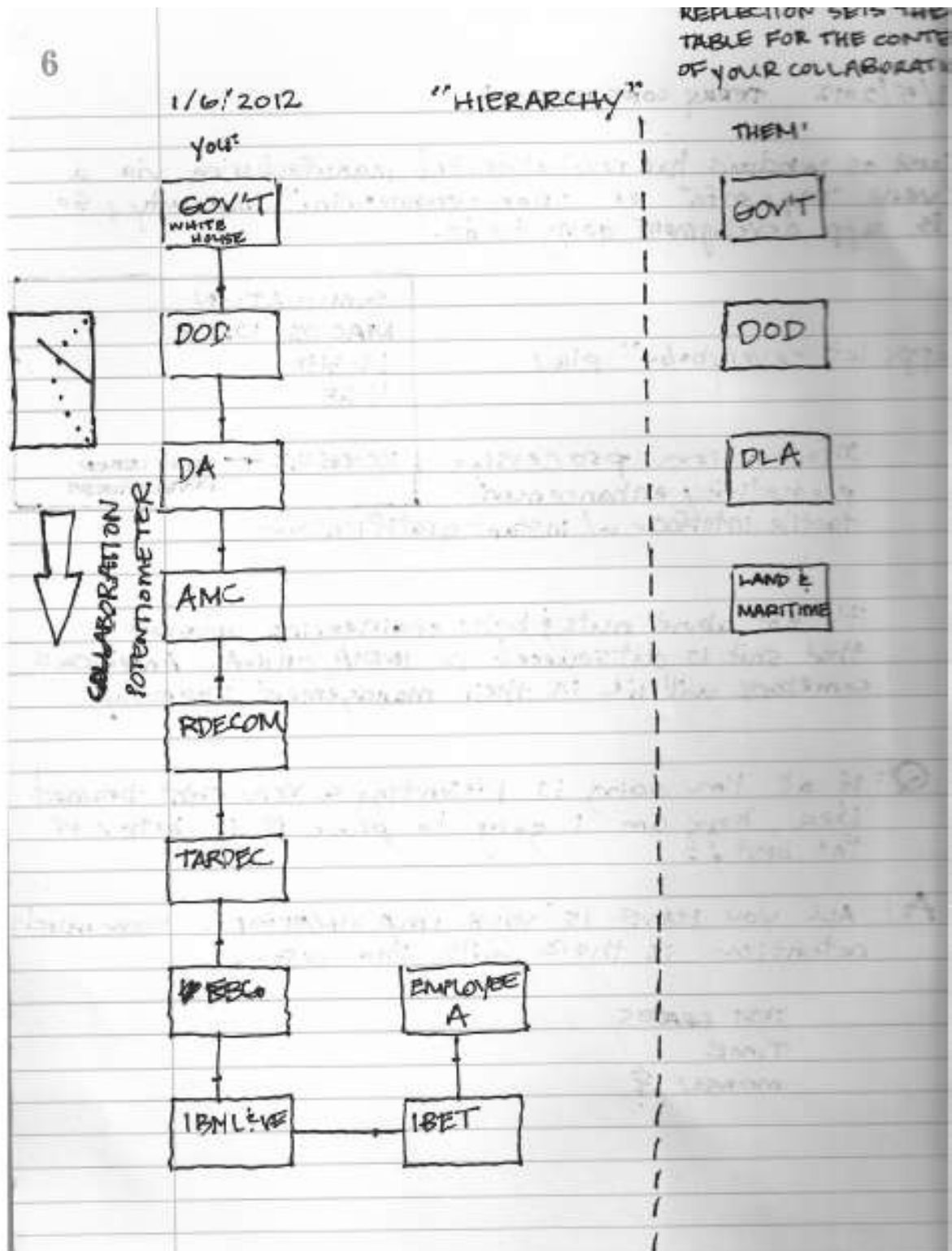
UNCLASSIFIED

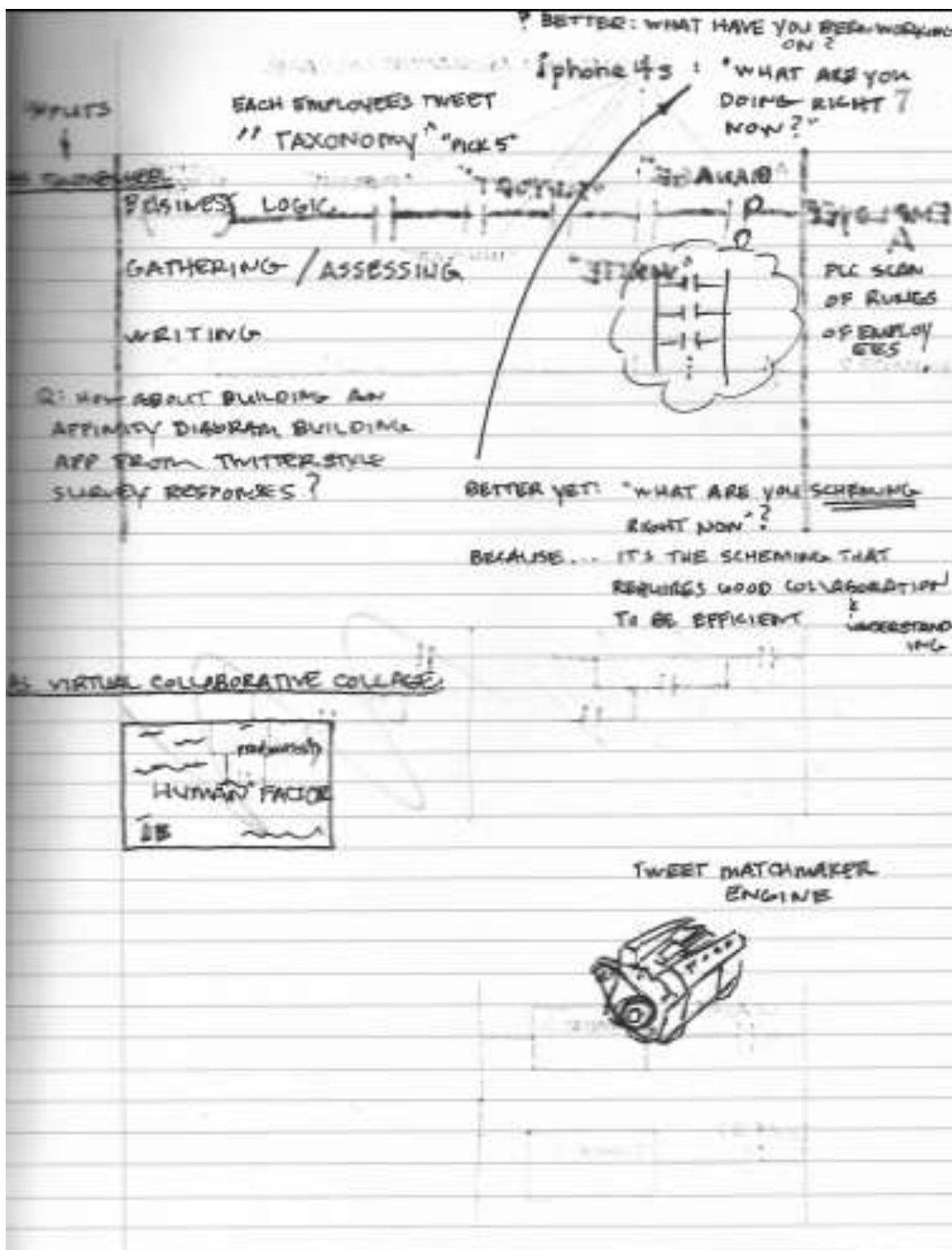
Journal of Aerospace Engineering Electrification of Aircraft Systems - Power and Control

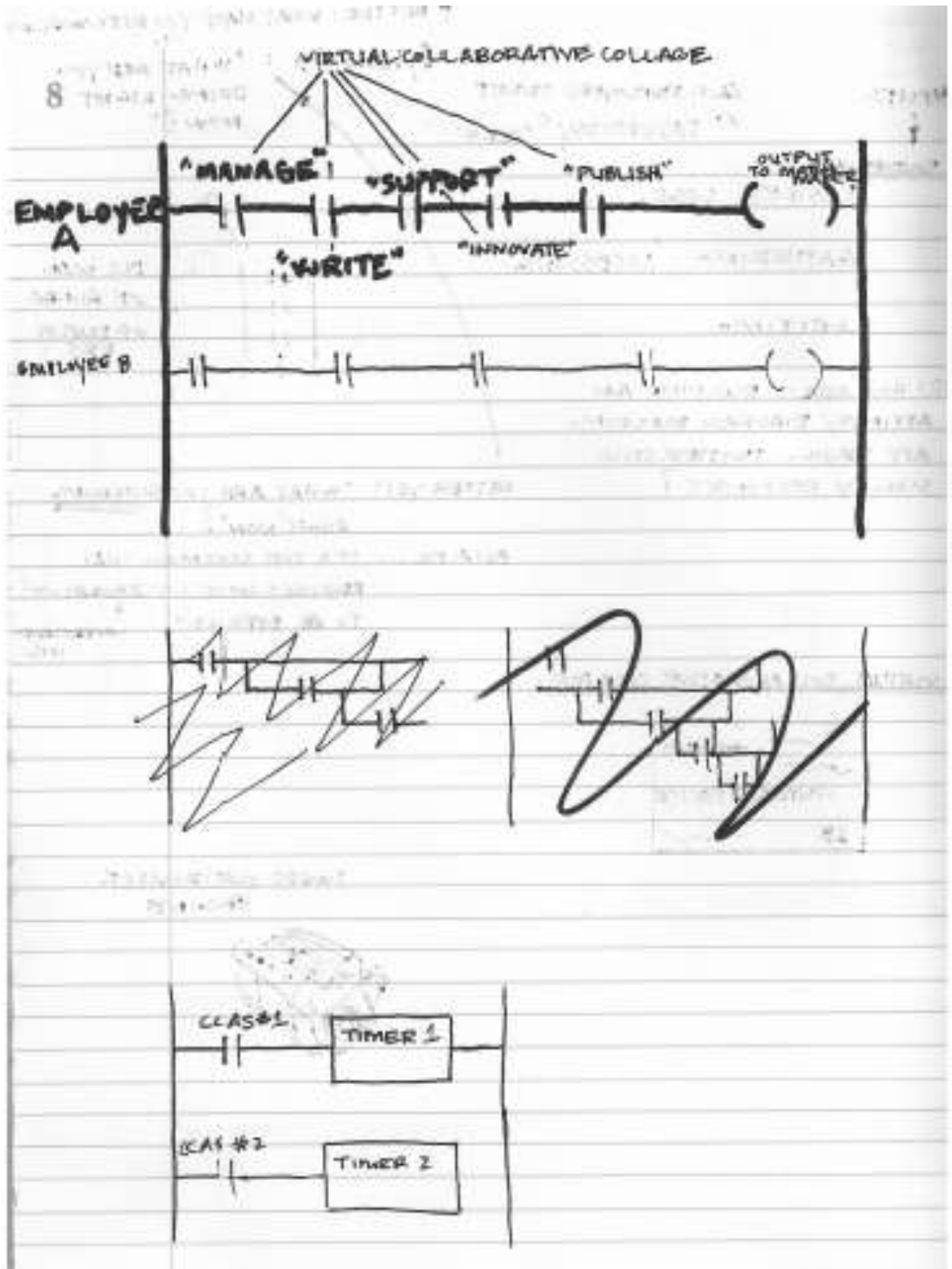
International Journal of Intelligent Unmanned Systems

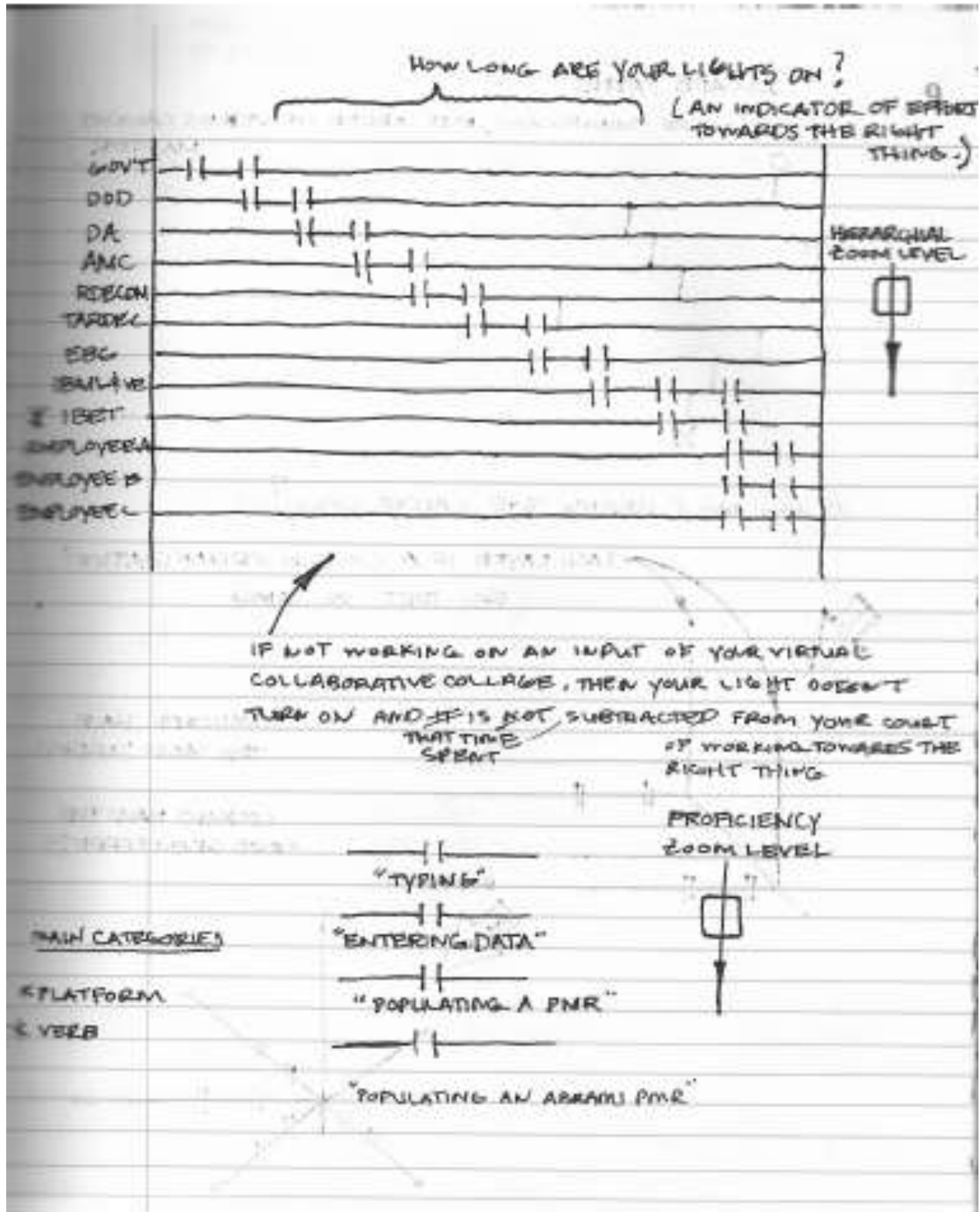
Appendix B

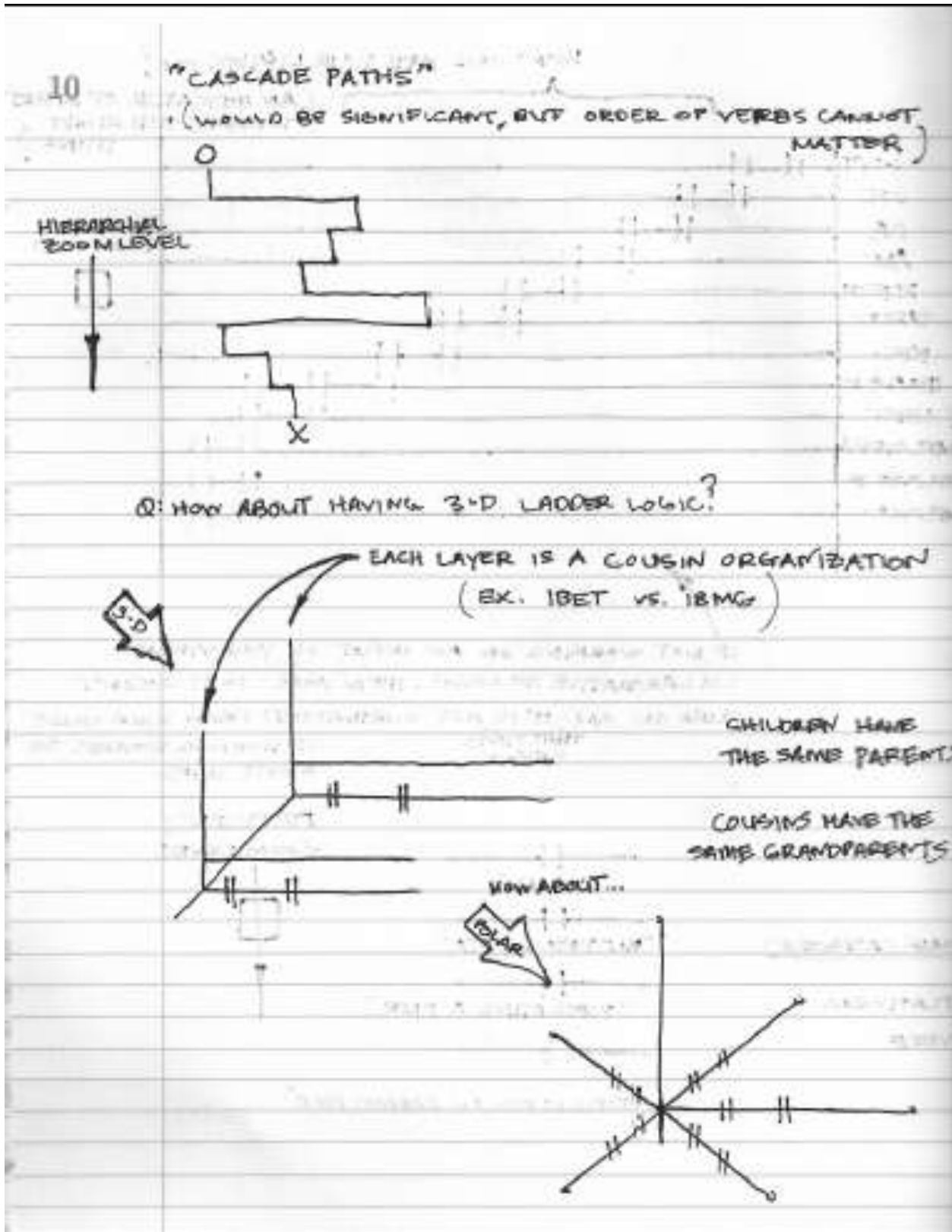


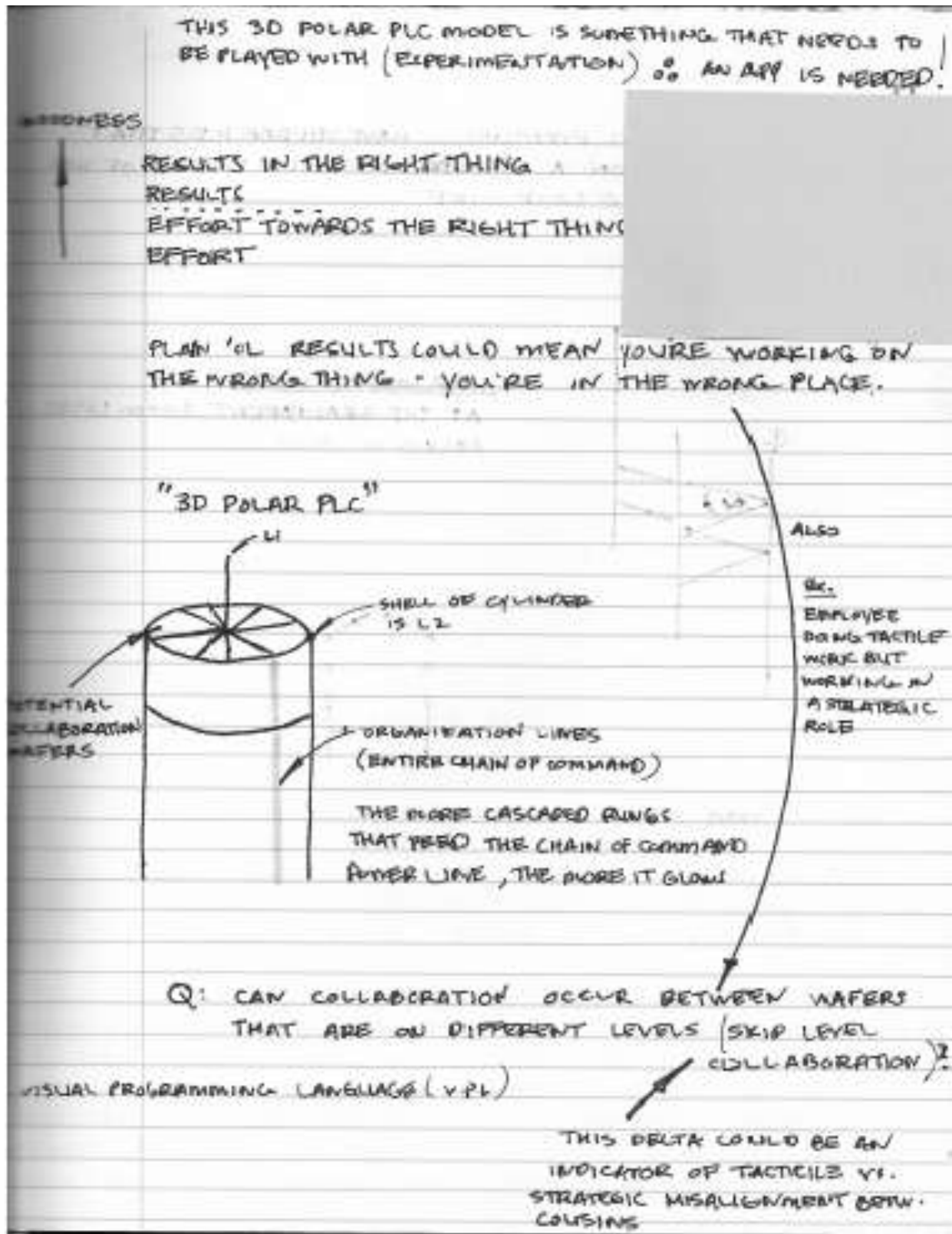






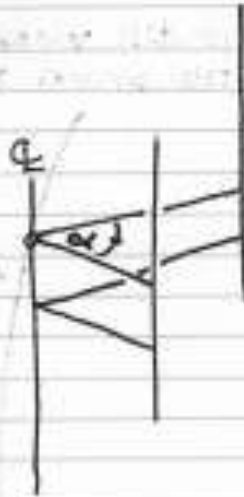






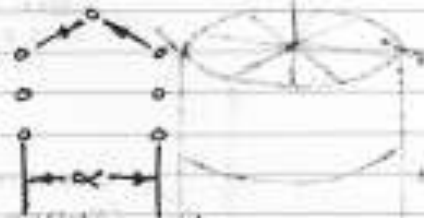
12

SINCE COUSINS EVENTUALLY HAVE HIERARCHIES THAT CONVERGE UPON A GRANDPARENT, THE PORTION OF THE MODEL WOULD LOOK LIKE:



FOR COUSINS' ONLY

AT THE GRANDPARENT ZOOM LEVEL
ANGLE $\alpha = 0$



THUS, SINCE COUSINS EVENTUALLY HAVE HIERARCHIES THAT CONVERGE UPON A GRANDPARENT, THE PORTION OF THE MODEL WOULD LOOK LIKE:

1-9-2012

13

FOLKS ARE ALREADY REQUIRED TO TELL WHAT THEY'RE WORKING ON, SO THIS IS NOT PIE-IN-THE-SKY. EG: BAE ACCOUNTS FOR EVERY 6 MIN (1/10 HR). EVERYONE'S RESP. FOR UPLOADING THEIR OWN SHIT.

VARIATIONS IN WORD INTERPRETATIONS WILL BE THE CHALLENGE.

ABSOLUTES:SUBJECTIVE:

WHAT YOU'RE WORKING ON
WHAT THEY'RE WORKING ON

COLLABORATION POINT

DATING BACK TO ANCIENT TIMES, THE RULE OF LAW STATES THAT A SOCIETY'S DECISIONS SHOULD BE BASED ON A STANDARD SET OF LAWS, RATHER THAN ON ANY ONE LEADER OR JUDGE'S DISCRETION. BY APPLYING THESE LAWS EQUALLY AND OBJECTIVELY TO ALL PEOPLE, A SOCIETY CAN AVOID ABUSES OF POWER.

SOCIAL CONTRACT THEORY IS A FRAMEWORK FOR ANALYZING INDIVIDUALS AND THEIR GOVERNMENTS, WHICH IS DESCRIBED IN THE WRITINGS OF PHILOSOPHERS JOHN LOCKE, THOMAS HOBBES, AND JEAN-JACQUES ROUSSEAU. IT DESCRIBES GOV'T AS A CONTRACTUAL RELATIONSHIP BETWEEN INDIVIDUALS AND THE STATE, IN WHICH INDIVIDUALS GIVE UP THEIR ABSOLUTE FREEDOMS IN EXCHANGE FOR COLLECTIVE BENEFITS.

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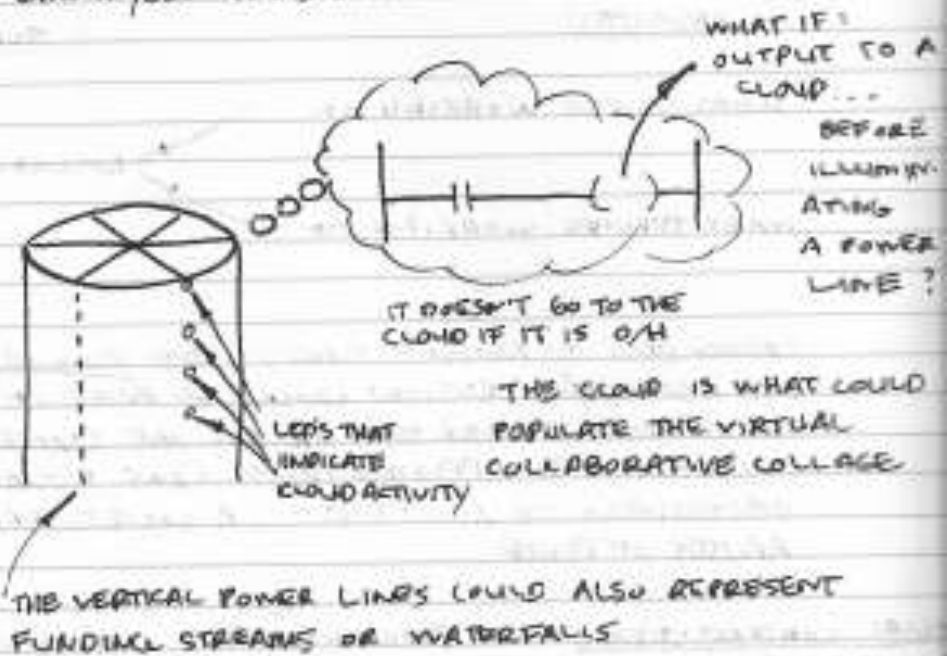
MEASURE HOW LONG STAY ON TOPIC.

Q: ARE CONSTANT TOOL CHANGES BAD? ^{TOPIC}

Q: SHOULD COLLABORATION POTENTIAL ONLY BE TRIPPED WHEN TOPIC IS CONSTANT OVER A MINIMUM PERIOD?

ASSUMPTION:

- * ALL GROUPS HAVE VISIONS/MISSIONS/OBJECTIVES
- * ALL EMPLOYEES HAVE GOALS



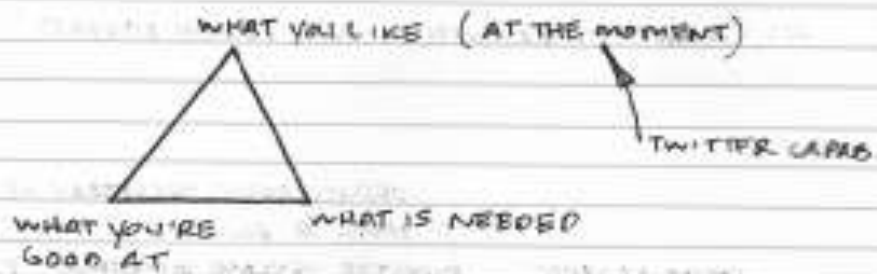
USE TITLE III SITUATION AS AN EXAMPLE:

WE WOULDN'T HAVE KNOWN ABOUT THEM
THEY WOULDN'T HAVE KNOWN ABOUT US.

NOW... FOR SOMETHING ENTIRELY DIFFERENT...

WHEN IPHONE CALLS YOU AND ASKS WHAT YOU'RE WORKING ON,
YOU PICK ONE OF YOUR GOALS AND UPLOAD THAT VERBIAGE TO
THE CLOUD (NO 3D LADDER LOGIC NEEDED)...

Q. HOW CAN WE INCORPORATE AN EMPLOYEE'S RESUME INTO
THE MIX?



AGAIN, THOSE ARE ALL RELATIVE, ESPECIALLY WHAT YOU'RE
GOOD AT...

WHAT YOU'RE GOOD AT HAS 2 DISTINCT WORLDS:

1. WHAT YOU'RE GOOD AT THAT IS PRESTIGIOUS
2. WHAT YOU'RE GOOD AT THAT YOU'D BE A FOUL TO ADMIT

→ NORTH AMERICAN TECHNOLOGY AND IS
ORGANIZATION (NATIBO)

EX. DIRECTING
PLATFORMS
EX. CLEANING TOILETS
OR TYPING IN
RAW DATA

→ NATIONAL SCIENCE & TECHNOLOGY COUNCIL - LEADS SET POLICY
ACROSS THE DIVERSE ENTITIES THAT MAKE UP THE FEDERAL R&D ENTERPRISE

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MORE
TO GO
GVSETS

IMPROVE THE VALUE AND PRESENTATION OF
Q: WHAT ABOUT ENHANCING THE SA, OF AN OFFICE ENVIRONMENT
USING SENSORS, ...
BY LEVERAGING THE (C4ISR, ELECTRONIC WARFARE) SYSTEMS
WITH NETWORKS

Q: IS PROVIDING A FRAMEWORK ENOUGH TO SATISFY
DEMS?

Q: AREN'T EXPERIMENTS AND PROOF NEEDED?

DEPUTY ASSIST. SECRETARY OF DEFENSE FOR
MFG IS POLICY

BRETT LAMBERT - DIRECTOR DEFENSE INDUSTRIAL POLICY

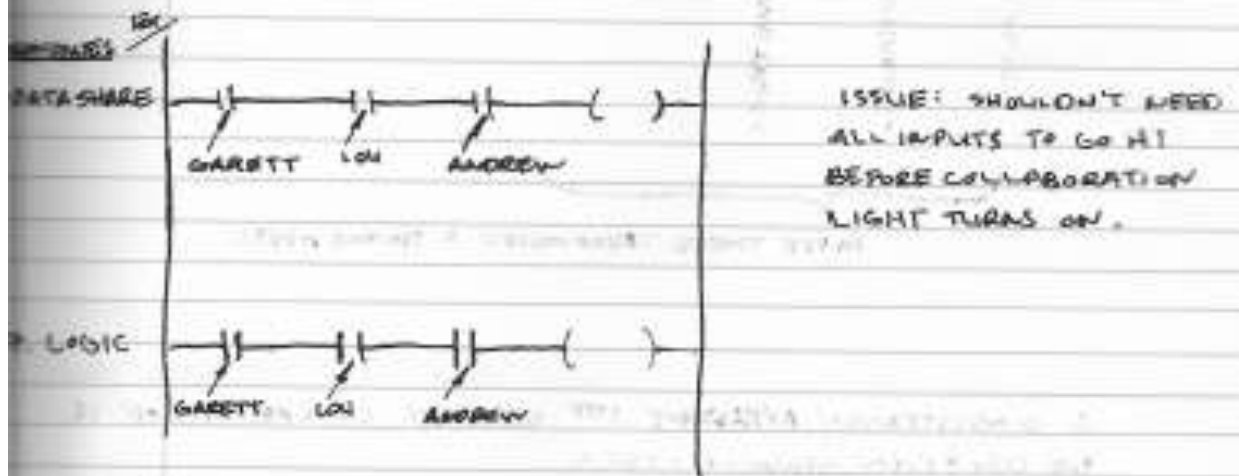
SRIDHAR KOTA - ASSIST. DIRECTOR ADVANCED MANUFACTURING POL.
OFFICE OF THE PRESIDENT WHITE HOUSE OFFICE OF
S&T POLICY

ANBENA CHOPRA - UNITED STATES CHIEF TECHNICAL OFFICER
PRESIDENT'S OFFICE OF S&T POLICY

'TYPING' COULD BE A GREAT-GRANDPARENT CATEGORY OF A SPECIFIC TASK OR IT COULD BE CONSIDERED AS THE MOST ELEMENTAL BREAKDOWN OF A SPECIFIC TASK

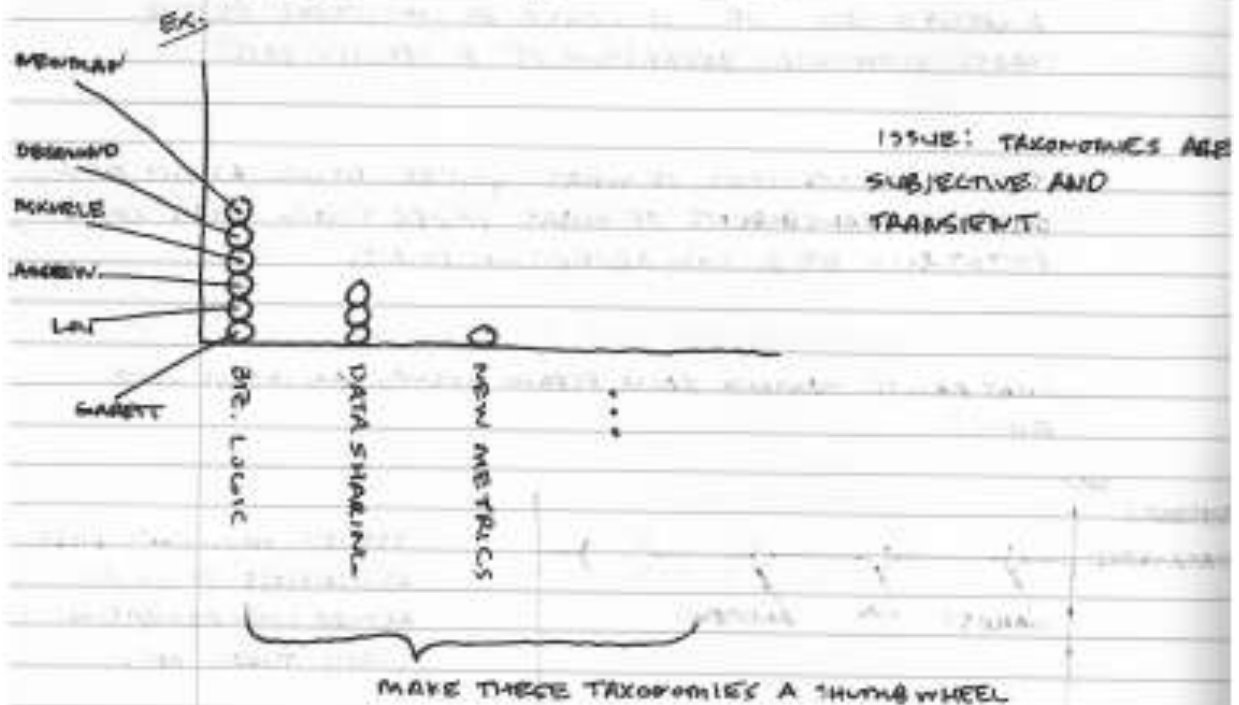
IT'S NOT THE SPECIFICS OF WHAT YOU'RE DOING RIGHT NOW, BUT THE GRANDPARENT OF WHAT YOU'RE DOING THAT COULD POTENTIALLY BE A COLLABORATION POINT.

WHAT ABOUT HAVING EACH PERSON OCCUPY AN INPUT ON A RUMBA?



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WHAT ABOUT INSTEAD OF A 3D LAYERED LOGIC MODEL,
YOU JUST HAVE A DOT PLOT MODEL:



A CONSISTENTLY APPARENT 1ST STEP IN COLLABORATION IS
THE DOG & PONY SHOW - N - TELL

TOO BAD TEAMS CAN'T JUST UPLOAD ELEVATOR SPEECH DEMOS
UP TO YOUTUBE FOR PEOPLE TO SHOP FROM WHEN
SEARCHING FOR COLLABORATION POINTS.



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Q: WHAT ABOUT MAKING AN AFFINITY DIAGRAM APP?

ANS: EXPERTS WILL SUGGEST CATEGORIES THAT OTHERS AREN'T EXPERIENCED ENOUGH TO APPRECIATE (EX LOGISTICS, DIMENSIONAL MGT.)

Q: WHAT ABOUT USING DESIGN STRUCTURE MATRIX (DSM) TO MODEL COLLABORATIVE PARTNERSHIPS??



BOTH SIDES OF A COMBINATIONS FALL ON EITHER SIDE OF THE 45° LINE

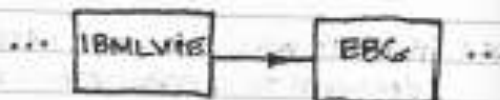
THE FURTHER APART THE LETTERS OF THE COMBINATION, THE FURTHER FROM THE 45° LINE THE 'X' WILL LIE. IT TENDS TO FILL THE SPACE GIVEN

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IF A HQ DEPENDS ON ITS DEPARTMENTS, IT CAN BE
THOUGHT OF AS AN INVERSE PROCESS

IBET
IBMLVIE
EBG
TARGET
ROECON

IBET
IBMLVIE
EBG
TARGET
ROECON

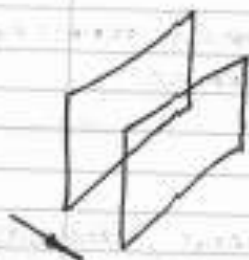


OBSERVATION: CLOSER TOGETHER AT
THE TOP ~~AND~~ TRANSLATES TO THE
45° LINE DIVING DOWN
FASTER AND ENDING SHY.

ISSUE: BREAKING FREE FROM
CHAIN OF COMMAND WOULD HAVE
TO BE CONSIDERED "DESIRABLE"
FROM AN INTERDEPENDENCIES POV
SO THAT DOESN'T MAKE SENSE.



IF THE DSM WERE 3-D, INSTEAD OF GOING FROM POINT TO
POINT ALONG THE SEQUENCE, YOU'D HAVE TO GO PLANE TO PLANE
AND INSTEAD OF STRIVING TOWARDS THE 45° LINE, YOU'D HAVE
TO STRIVE TOWARDS THE CENTER OF A CUBE.

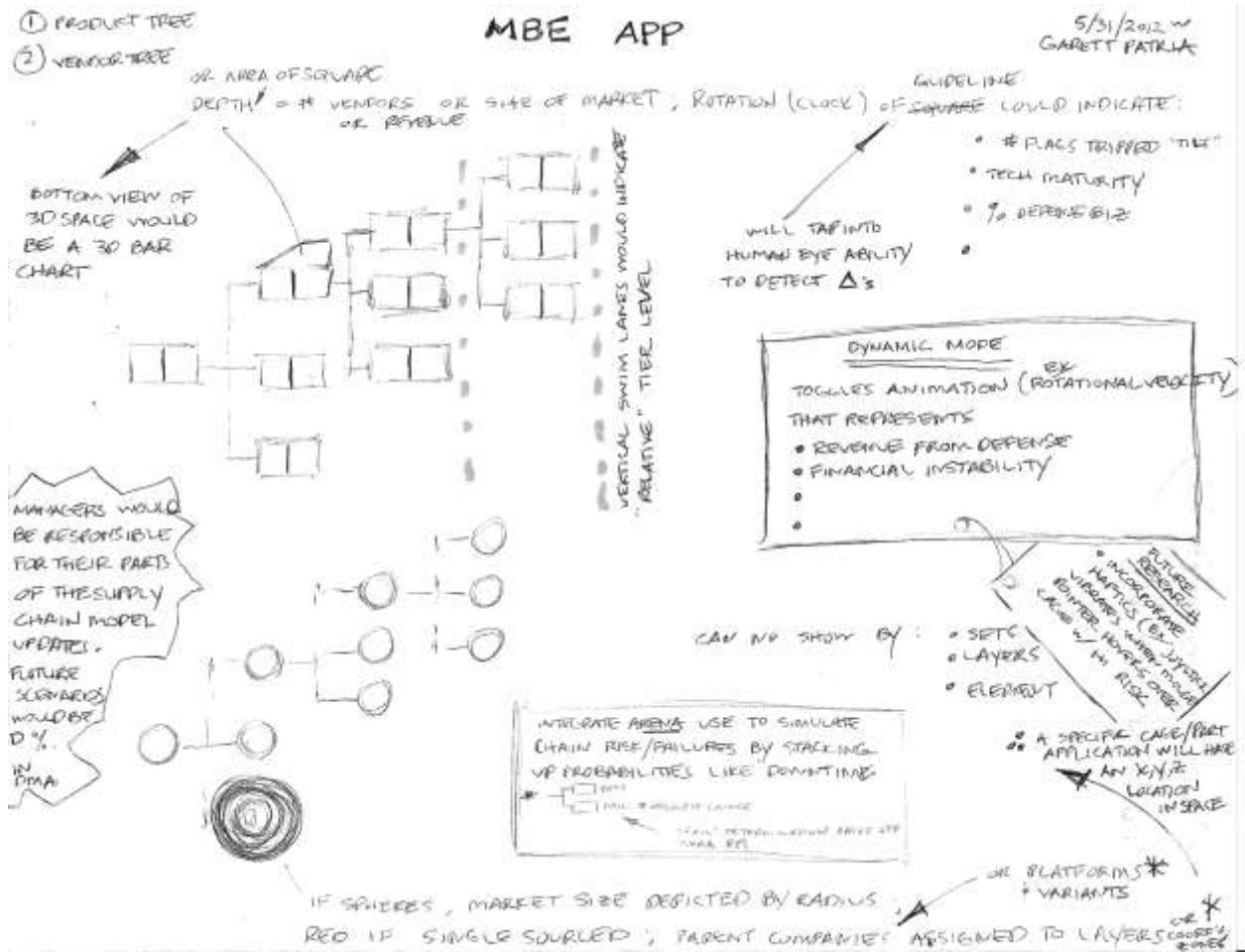


Q: WHAT WOULD THE 3RD DIMENSION BE?

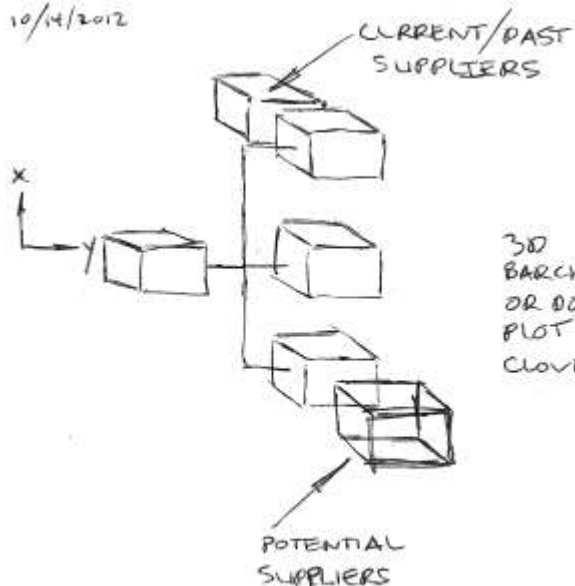
RECALL THE BINARY EFFICIENCY MATRIX FROM WARREN TRUCK:

	TIME1	TIME2	...
INFLUENCE1	0	1	
INFLUENCE2	1	1	
...			

A NOVEL WAY TO LOOK AT OPPORTUNITIES (EVEN $n/18$)
IS TO LOOK AT THREAT DETECTION



10/14/2012



FOR VIEW

DEPTH IN \oplus Z DIRECTION INDICATES MULTIPLE SOURCES

3D BAR CHART OR DOT PLOT POINT CLOUD

DEPTH IN \ominus Z DIRECTION INDICATES UNTAPPED SURROGATE INDUSTRY

VISUAL SORT POINTS:

* COLOR (RED VS. B/W)

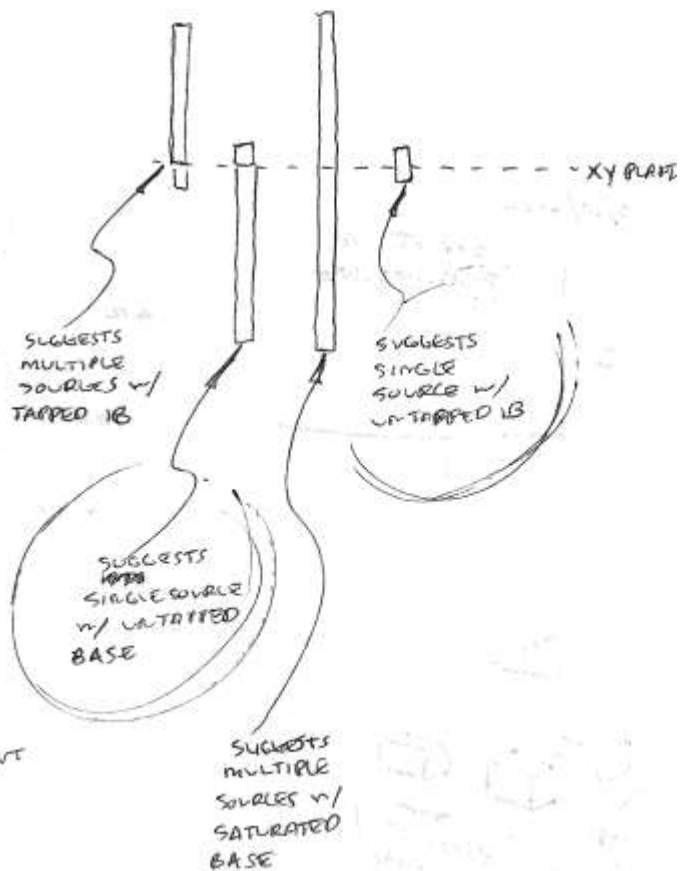
* ANIMATION (CW VS. CCW)
(SHIVER VS. STATIC)

* GEOMETRY (CUBE VS. SPHERE)

* FORM (PEAKS VS. VALLEYS)

LAYERS, SETS, FILTERS

CAGE/PAST APPL. WILL HAVE A POINT IN CLOUD $\sim (X, Y, Z)$ I.D.



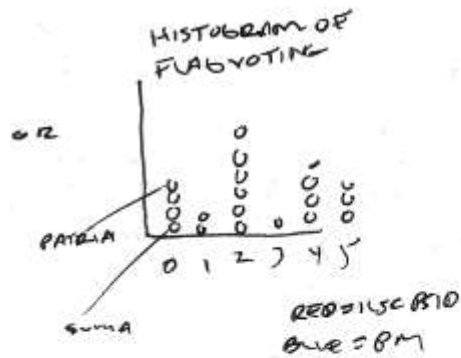
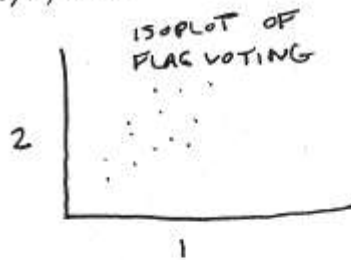
10/4/2012

RESPONSE
OUTPUT % RPI

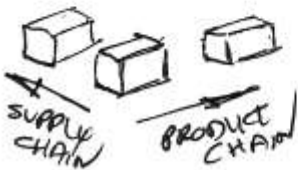
INPUTS
INDIV. RPI's
FSC COUNT



10/10/2012



3D



Appendix C

15	min/day	0.25	hrs/day	
220	days/yr			
\$ 50	\$/hr			
\$ 2,750	\$/yr/analyst			
200	analysts			
\$ 550,000	\$/yr/pack of 200 analysts			
20000	NIINs	with 1/2 being DLA managed		
100	NIINs/analyst			
11000	TACOM suppliers			
55	suppliers/analyst			
~ 1 supplier/week/analyst				
~ 1hr/supplier/yr/analyst				